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Modular Multipurpose Space Station Study

Section 5-MULTIPURPOSE SPACE STATION APPLICATIONS

Section 6-DEVELOPMENT PLAN

FINAL REPORT

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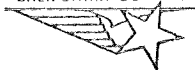
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VOLUME INDEX

MODULAR MULTIPURPOSE SPACE STATION STUDY

The complete study, consisting of six sections, an appendix, and a condensed summary, is contained in the following seven volumes.

- { 1. INTRODUCTION
- { 2. TECHNICAL SUMMARY
- { 3. MODULAR SPACE STATION DESIGN
 - 3.1 Modular Configurations
 - 3.2 Radiation Shielding
 - 3.3 Structural Design
 - 3.4 Weight Analysis
 - 3.5 Subsystems
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 - 3.7 Special Subsystem Studies
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Section 5

MULTIPURPOSE SPACE STATION APPLICATIONS

Experiment and application requirements and the capability of the Modular Multipurpose Space Station configurations to meet these requirements are discussed in Sections 5.1 through 5.5.

Experiments specifically selected for the Apollo Extension System (AES) flights are analyzed in Section 5.1. Two interior layouts are presented showing the placement of AES experimental equipment in a single modular compartment; one layout combines the experimental equipment of flights 218 and 219; and the second, flights 523, 229, and 230.

A total of 405 earth-orbiting space station applications were described and assessed as to the requirements imposed upon the candidate laboratories and space stations. These requirements are summarized by individual application in Section 5.2.

Scheduling of the experiments and applications requires a computer solution to achieve desirable efficiencies of utilization of manpower and electrical energy. A computer program to accomplish this scheduling is described in Section 5.3. Typical application performance schedules are given for the Multipurpose Space Station configurations.

Allocation of experiments to specific locations within the individual compartments of the Interim Modular Multipurpose Space Station is given in Section 5.4. Four interior layouts, one for each of the inner compartments, are shown; the living quarters compartment and the subsystems compartment, which can become standard space station elements, are described in Section 3.1.

The interface between the experiments and the accommodating space station is discussed in Section 5.5. Primary considerations for application/space station integration are mentioned; consideration of the subsystem performance in support of these applications is also given.



5.1 AES PRIORITY I EXPERIMENTS

The NASA has selected 85 experiments which are to have preference in assignment to the anticipated Extended Apollo Earth-Orbit Flights. Preliminary descriptions of these experiments were supplied to Lockheed for the definition of the required development cycles necessary for the development of the experiment equipment at a time consistent with specified vehicles and flight schedules. This was a supplementary task substituted for a part of the original study work statement.

The preferred, or Priority I, experiments are grouped in 16 major categories with the number of individual experiments in each category as given below:

<u>Category</u>	<u>Title</u>	<u>Number of Experiments</u>
1	Medicine	21
2	Behavior	3
3	Creation of Artificial Gravity	2
4	Living Organisms	6
5	Space Environment	4
6	Liquid/Gas and Solids Behavior	8
7	Astronomical Observations and Techniques	6
8	Remote Sensing of the Earth's Atmosphere	5
9	Remote Sensing of the Earth's Surface	3
10	Maneuverable Sub-satellites	1
11	Launch of an Unmanned Satellite	1
12	Electromagnetic Propagation and Transmission	2
13	Space Structures Technology	6
14	Subsystem Development and Test	7
15	Extra-vehicular Operations	7
16	Maneuvering and Docking	3

The experiment development requirements task was approximately 60 percent complete when a redirection of study effort terminated this particular

phase. Although this task was terminated before completion, one conclusion was becoming apparent: development time for the experimental equipment, with the required testing, integration and crew training, is even now becoming critical for a number of the experiments.

Selected to illustrate the experiment development requirements effort is Experiment 1402, "Cabin Atmosphere Control for LSS"; Fig. 5-1 is the experiment development cycle showing the necessary steps to be taken and their interrelationship. Figure 5-2 depicts the phasing of the development tasks necessary to complete the experiment in time for the suggested first flight date.

An "Experiment Flight Assignment Summary", prepared by NASA-MSC, Table 5-1 was used as a basis for subsequent figures and tables in this section. Flight numbers in the 200 and 500 series represent Saturn IB and Saturn V launches, respectively.

A study was performed to assess the ability of the modular space station configurations to meet the requirements of the 85 AES Priority I experiments. Four requirements of the AES experiments were examined:

(1) weight, (2) volume, (3) man-hours and (4) electrical energy. Where other companies had different estimates of the experiment equipment, manpower, and electrical energy necessary to meet the NASA-stated experiment objectives, these differences are shown. The NASA schedule of flights designates specific experiments to be performed on the individual flights, and the aforementioned experiment requirements are also summarized by flight number.

Figure 5-3 shows the weight of experimental equipment required for the AES flights designated in Table 5-1. The line marked 'NASA' shows data given in NASA-Headquarters experiment descriptions dated March 15, 1965. Boeing, Grumman, and North American experimental equipment weight estimates (Ref. 1, 2, and 3) for these flights are also shown. Direct comparison is difficult since Grumman, for example, used a different selection of experiments for flights 218, 219, 516, 523, 229 and 230.

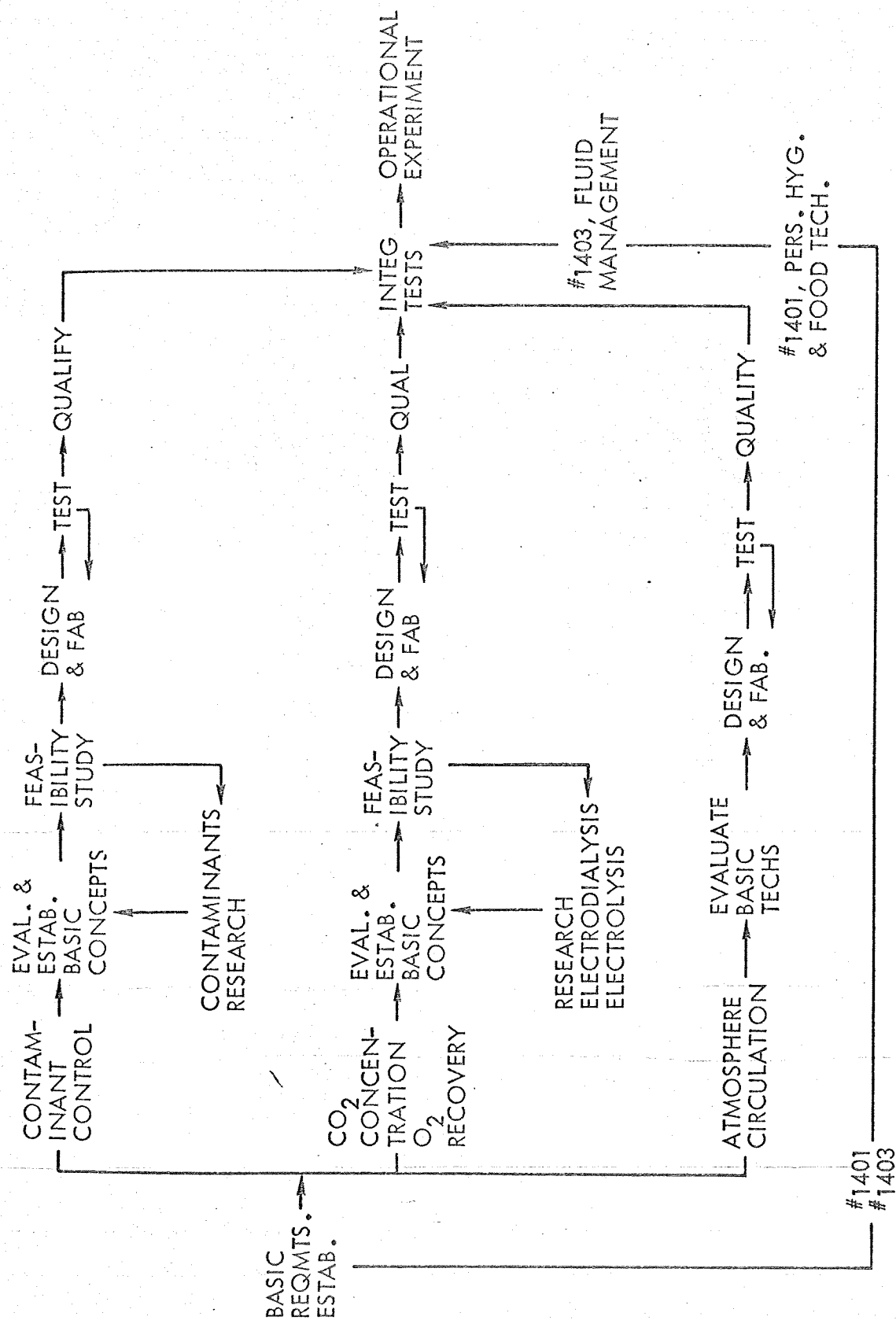


FIG. 5-1 DEVELOPMENT CYCLE EXPERIMENT 1402 CABIN ATMOSPHERE CONTROL FOR LSS

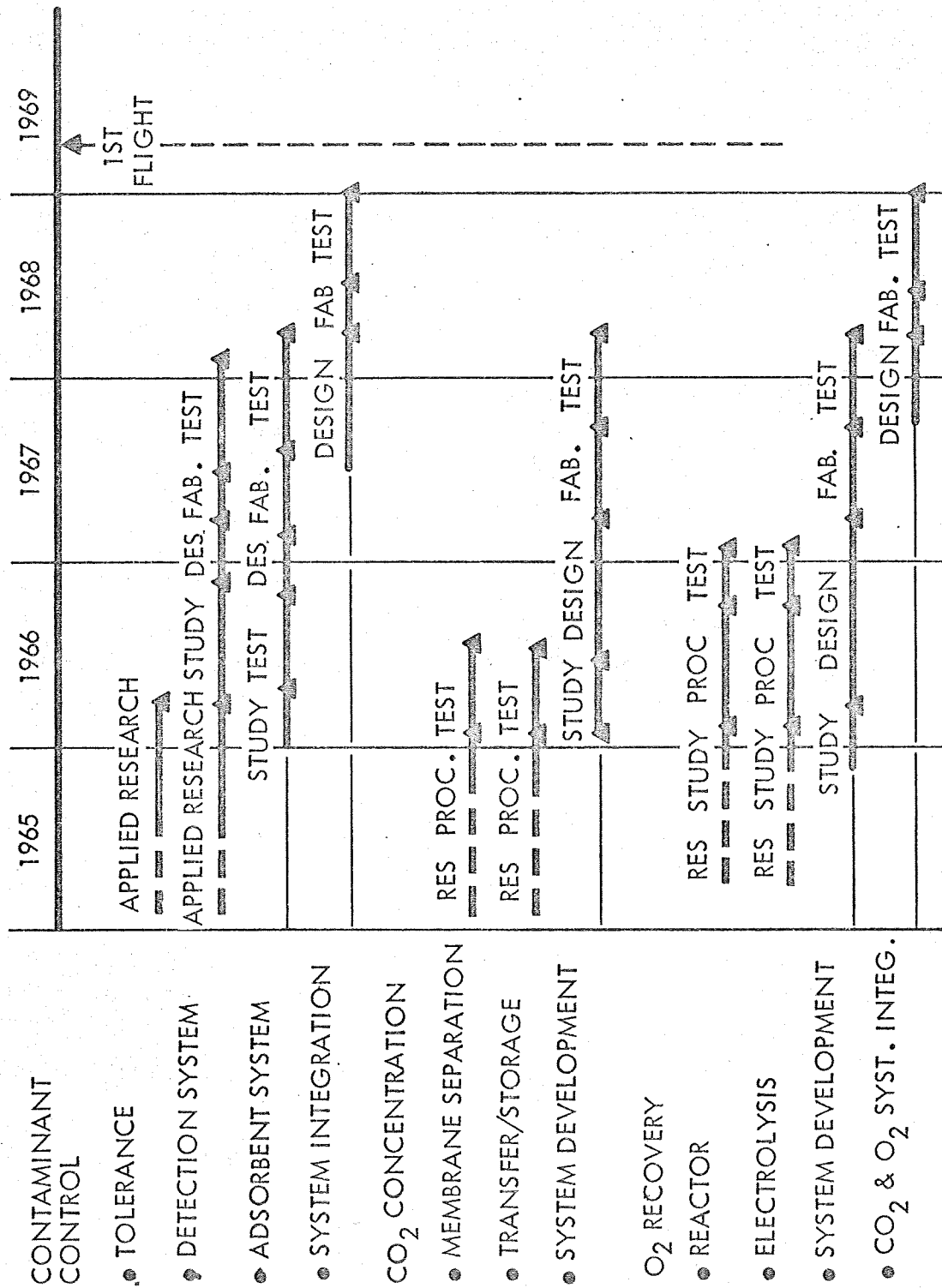


FIG. 5-2 DEVELOPMENT SCHEDULE EXPERIMENT 1402-CABIN ATMOSPHERE CONTROL FOR LSS



Table 5-1
EXPERIMENT FLIGHT ASSIGNMENT SUMMARY - MARCH 19, 1965 MSC SPACE STATION OFFICE

Flight No.	Altitude (n. miles)	Inclination (deg.)	Duration (days)	Expt. No.	Medical/Behavioral
209 200 28.5 14	X			0100	
211 200 28.5 30	X			0200	
507 200 90 14	X			0301	Artificial G by Rotating Station
509 19350 0 14	X			0302	On-Board Centrifuge
215 200 50 14	X			0401	Genetic Effects in Microorganisms
513 200 +81.5 14	X			0402	Effects of Space on Unicell Org & Animal Tissue
218 200 28.5 45	X			0403	Effects of Weightlessness in the Primates
219 200 28.5 45	X			0404	Limb Regeneration & Wound Healing
221 200 28.5 45	X			0405	Effects of Drugs on Mammalian Behavior
516 19350 0 45	X			0406	Space Borne Microorganisms
518 200 -83 45	X			0501	Radiation Environment Monitoring
521 19350 0 45	X			0502	Study of Magnetic Field Lines
523* 200 28.5 45	X			0503	Analysis of Comet-like Particulate Clouds
229 200 28.5 45	X			0504	Micrometeoroid Collection
230 200 28.5 45	X			0601	Capillarity Studies
				0602A	Kinetics & Dynamics of Vapor/Gas Bubbles
				0602B	Liquid Drop Dynamics Study
				0603A	Pool Boiling in Long Term Zero G Environment
				0603B	Nucleate Condensation of Fluids in Zero G
				0604	Density Gradient of Fluid at Near Critical St
				0605	Crystallization Studies
				0606	Cosmic Ray Emission
				0701	Emission Line Radiometry
				0702	Intermediate Size Reflecting Telescope
				0703	Manned Coronagraph
				0704	Nearby Solar-Like Stars in X-Rays
				0705A	Radio Astronomy 1-5 MCPS Range
				0705B	Radio Astronomy 1-5 MCPS using "V" Antenna
				0801	Conjugate Aurora and Airglow
				0802A	Test of IR Scanning Spectrometer
				0802B	Calibration & Eval. of Microwave Spectrometer
				0802C	Test of Prototype Star-Tracker
				0802D	Operation of H-R IR Radiometer Det. Equip.
				0901	Multispectral Target Characteristics
				0902	Synoptic Earth Mapping
				0903	Multifrequency Radar Imagery
				1001	Small Maneuverable Satellite
				1101	Launch of an Unmanned Satellite (OGO)
				1201	Measurement of Radio Frequency Radiation
				1202	Wide Band Width Transmission in Space
				1301	Effects of Space Environment on Structures
				1302	Deployment of RF Reflective Structures
				1303	Extendable Rod Performance Tests
				1304	Ops of Solar Sailing Pass. Comm. Satellite
				1305	Deployment & Obs. of Gravity Gradient
				1306	Large Aperture Space Erectable Antenna
				1401	Personal Hygiene & Food Technology
				1402	Cabin Atmosphere for LSS
				1403	Fluid Management Technology for LSS
				1404	Radioisotope-Thermoelectric Power System
				1405	Range and Orbit Determination
				1406	Orbital Test of Large Solar Cell Array
				1407	Optical Technology
				1407	On-Board Navigation & Guidance
				1501	Evaluation of Adv. Space Suit Assemblies
				1502	Development of Manned Locomotion & Maneuvering
				1503	Emergency Techniques, Eqp & Proc for Rescue Ops
				1504	Personnel & Cargo Transfer Operations
				1505	Maintenance & Repair Techniques
				1506	Propellant Handling Techniques
				1507	Extravehicular Assembly Operations
				1601	Orbital Maneuvering & Docking (Phase I and II)
				1602	Observation of Echo Satellite
				1603	Recapture of Syncom III

* This mission is nominally at 200 n. mile altitude; extra fuel shall be provided for short excursions above and below the nominal altitude.

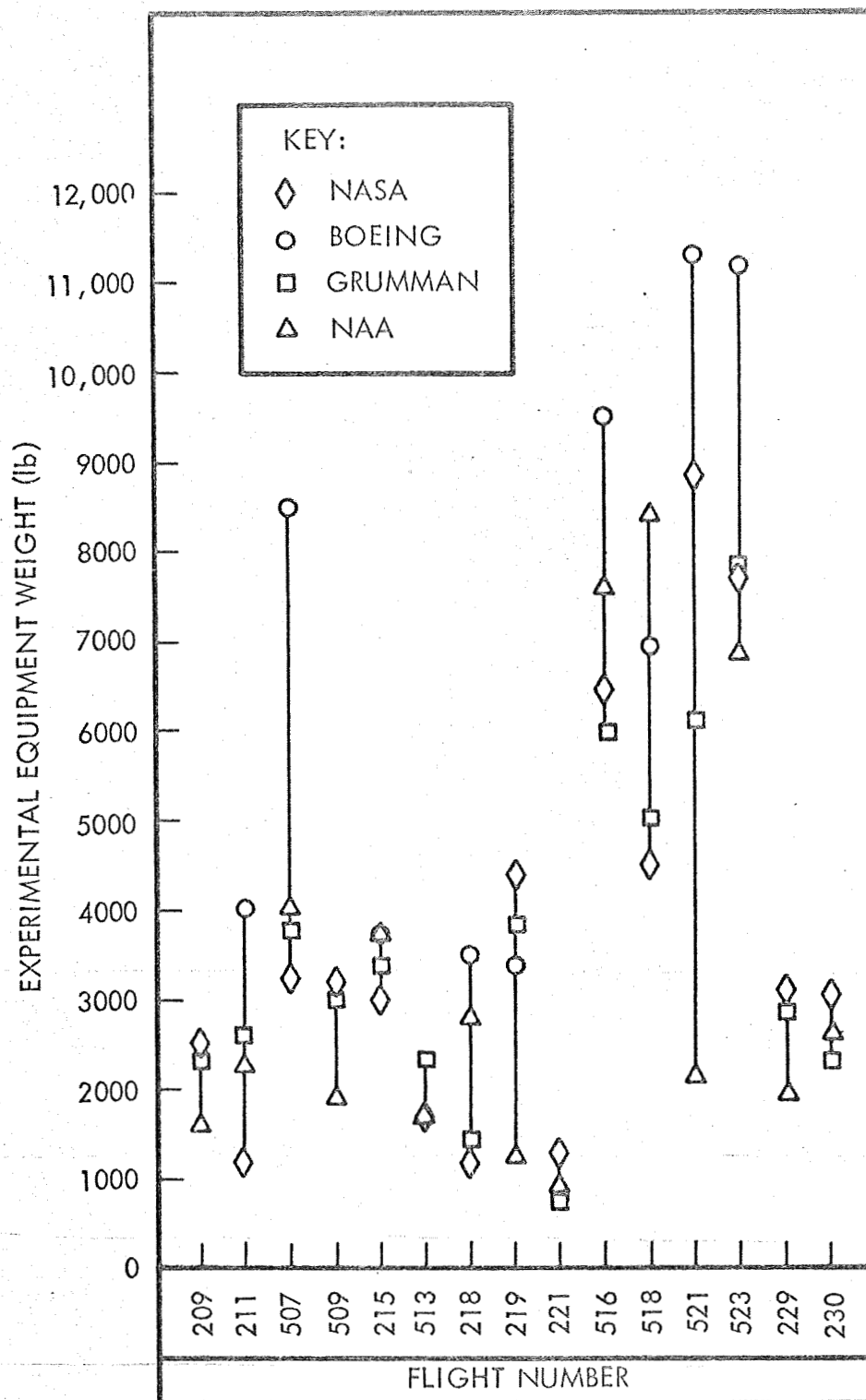


Figure 5-3 AES EXPERIMENTAL EQUIPMENT WEIGHT REQUIREMENTS

Stowed volume requirements of the AES experiments by flight number are shown in Fig. 5-4. The North American data appears to reflect the pressurized volume requirements, whereas the NASA values include pressurized and unpressurized volume requirements.

Man-hours required to perform the AES experiments by flight number according to the NASA data are shown in Fig. 5-5. Potential crew man-hours available for experimental activity are noted to be insufficient in view of these preliminary experiment requirements. Other study contractors have apparently reduced the experiment performance times to be compatible with experimental man-hours expected to be available on these early AES flights as shown in Fig. 5-6. As a result of Gemini flight experience, it is reasonable to anticipate that some degree of experiment automation will be needed to make the programmed experiments compatible with the crew time available.

Electrical energy required to perform the experiments becomes an important consideration in the assessment of the total AES experiment requirements because electrical energy represents weight in the case of a fuel cell power system and electrical power level represents weight where a solar cell power system is employed. The electrical energy required to perform the AES experiments is shown in Fig. 5-7 along with a reference line indicating the power expected to be available from the Apollo Service Module for experimental purposes.

Comparison of the payload capability of two of the modular space station configurations with experimental equipment weight requirements is depicted in Fig. 5-8. Selected configurations for this comparison were the One-Compartment Dependent Laboratory in low inclination earth orbit and the Two-Compartment Polar Orbit Laboratory. Flights 219, 518 and 523 are seen to be unobtainable with the candidate stations in their present configuration on the basis of available payload. However, a re-allocation of installed equipment and consumables may make these two configurations capable of accommodating these particular flight requirements. For example, Flight 219 has an excess of stored electrical

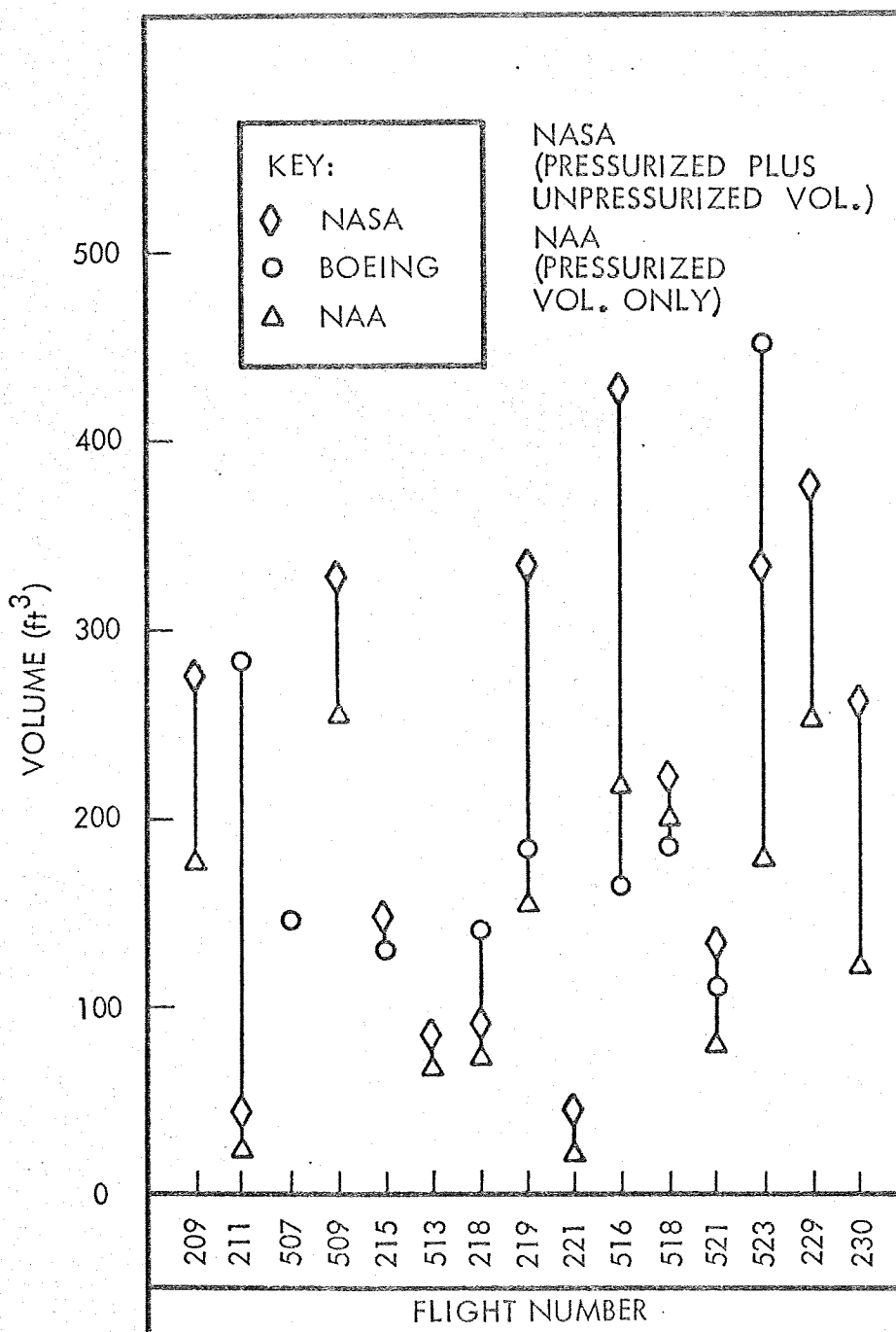


FIG. 5-4 AES EXPERIMENT STOWED VOLUME REQUIREMENTS

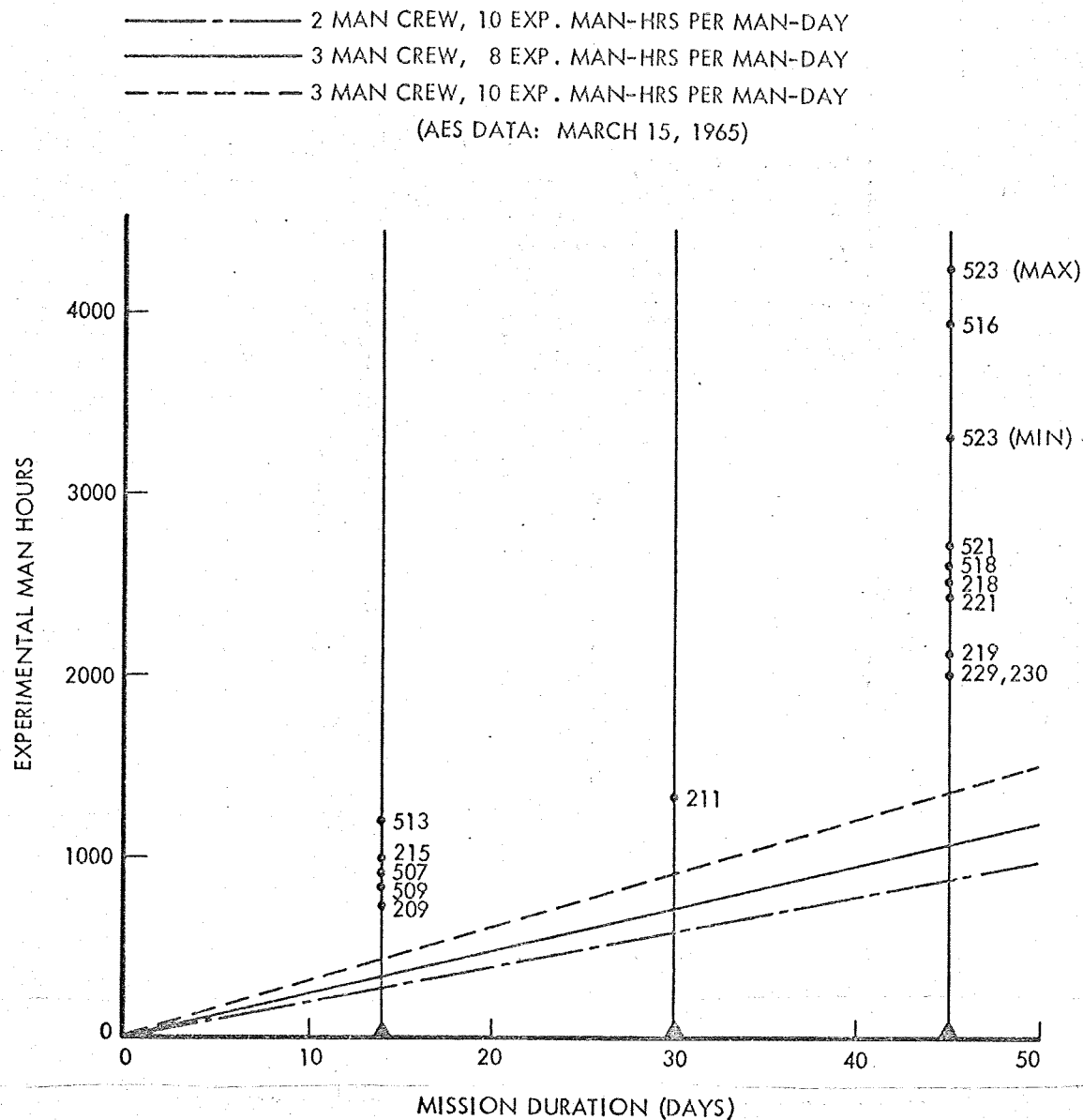


FIG. 5-5 MANHOUR REQUIREMENTS OF 15 AES FLIGHTS COMPARED TO POTENTIAL EXPERIMENTAL MANHOURS AVAILABLE WITH APOLLO VEHICLE AND CREW

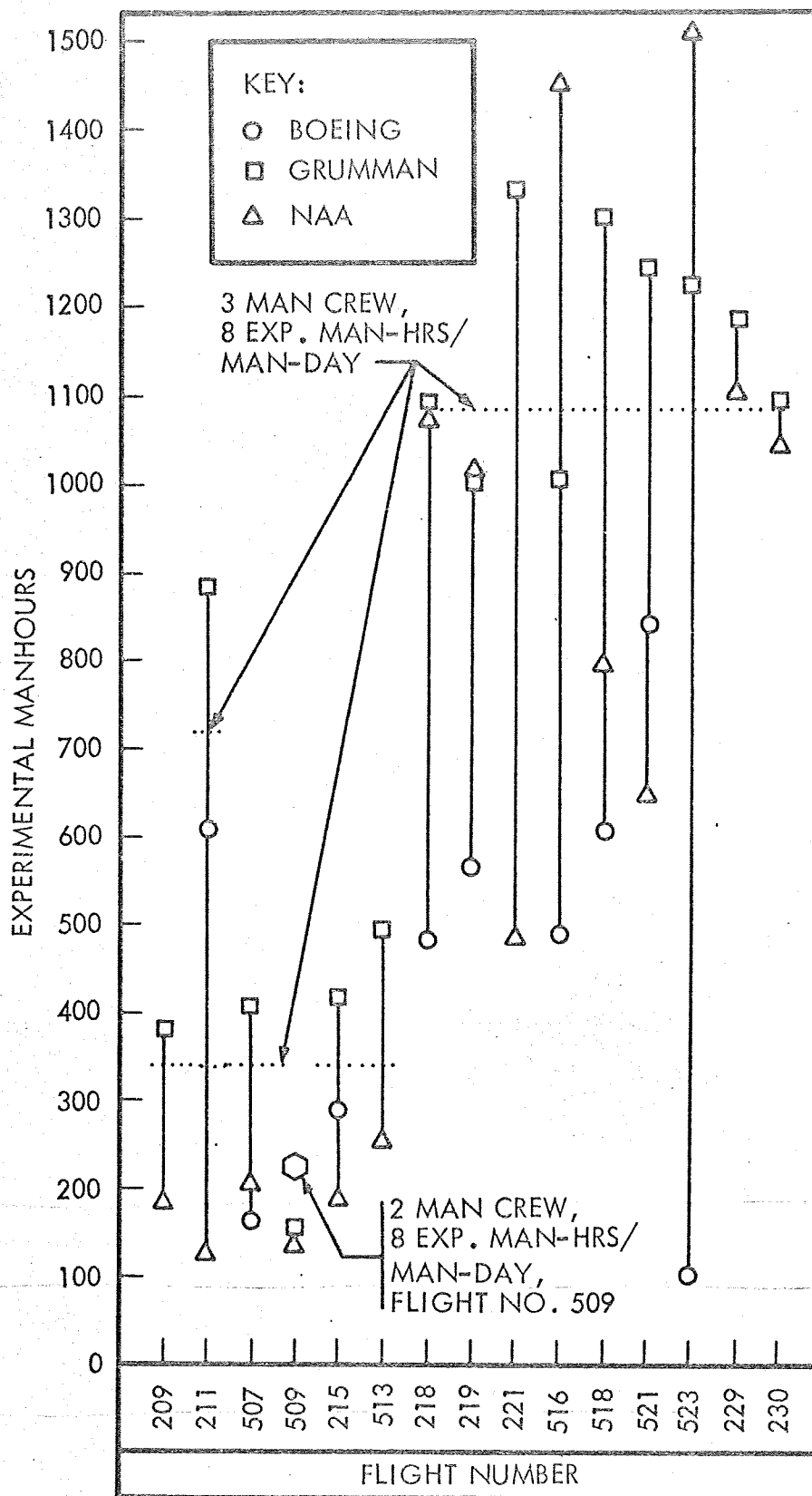


FIG. 5-6 AES EXPERIMENTAL MANHOURS REQUIRED

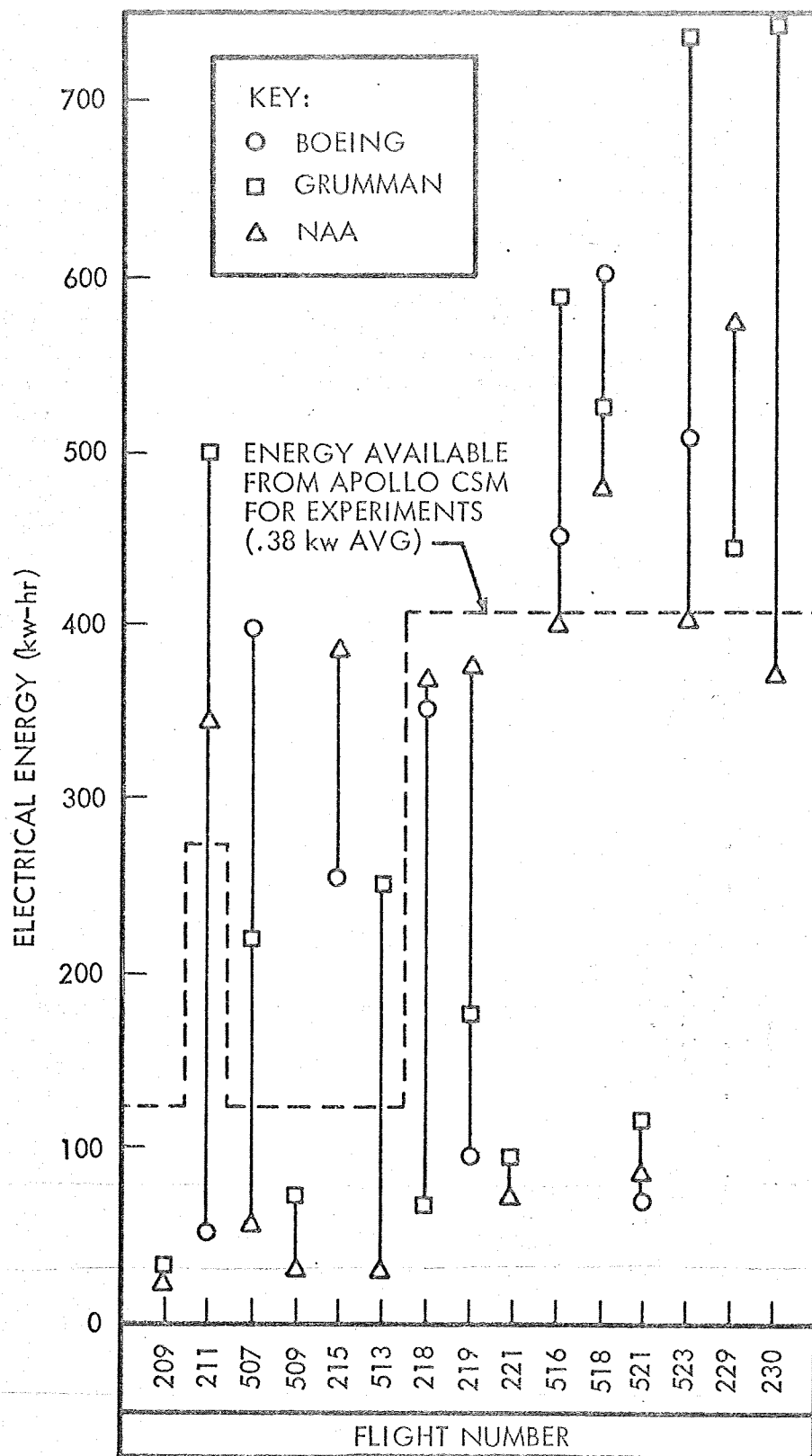


FIG. 5-7 AES EXPERIMENT REQUIREMENTS FOR ELECTRICAL ENERGY

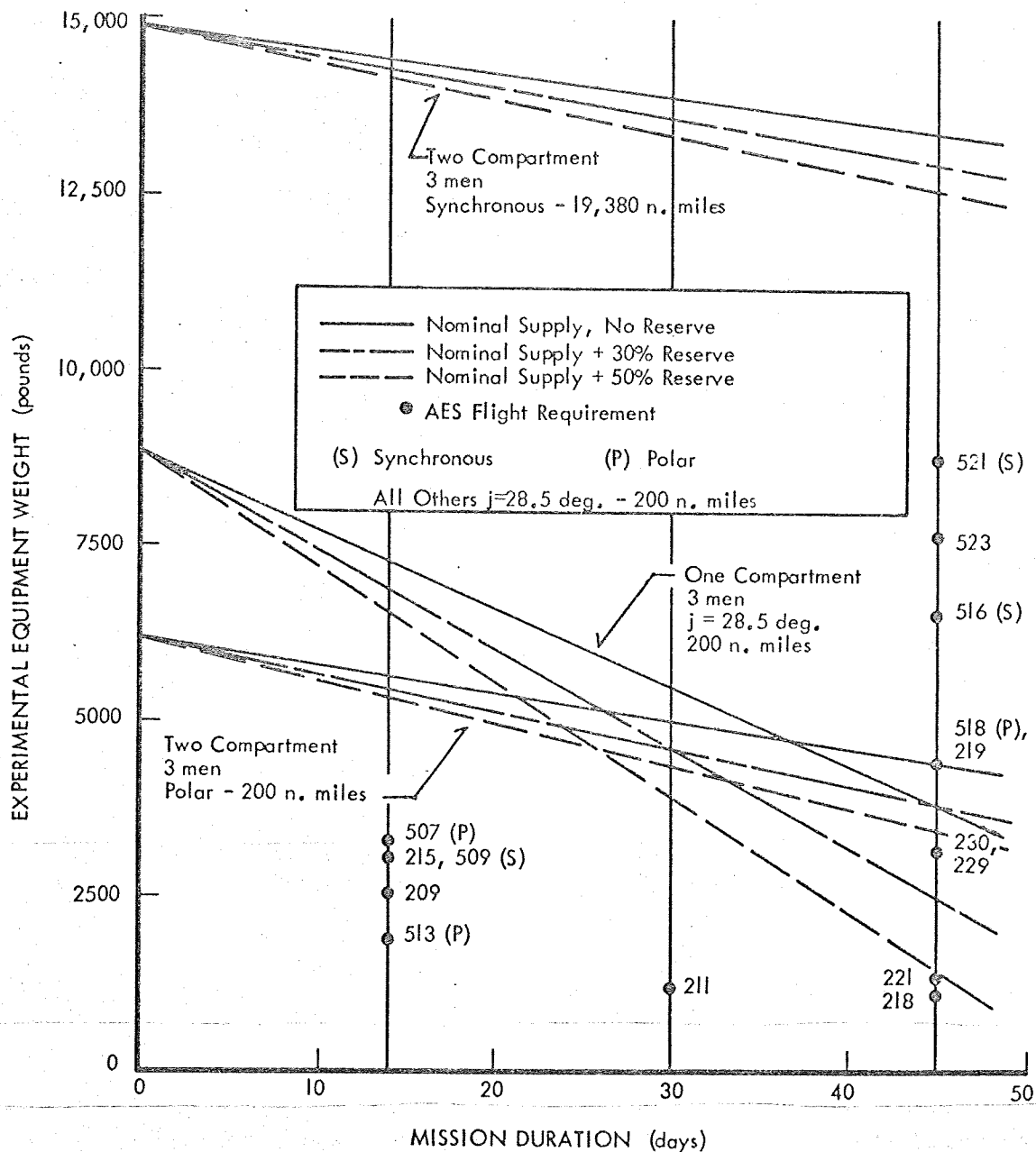


FIG. 5-8 EXPERIMENTAL EQUIPMENT WEIGHT REQUIREMENTS OF 15 AES FLIGHTS COMPARED TO EXPERIMENTAL PAYLOAD CAPABILITY OF SELECTED MODULAR APPROACH CONFIGURATIONS

energy in the form of fuel cell reactants as compared to the tabulated AES Priority I experiment electrical energy requirements. A reduction of this electrical energy capability would yield an increased equipment weight capability thus making the One Compartment Dependent Laboratory a potential vehicle for Flight 219.

In summary, the majority of the proposed low inclination AES flights could be accomplished with the One Compartment Dependent Laboratory on a payload available basis. All AES synchronous orbit flights could be achieved with the Two Compartment Laboratory of the modular approach specifically configured for that mission; all AES polar flights are achievable with the noted exception of Flight 219.

The capability of a space vehicle to accommodate experiments based on volume requirements and volume available is more difficult to assess than are the other noted parameters of weight, man-hours and kw-hr requirements. Experiment volumes can be tabulated in various categories: 'stowed', 'deployed or in an operational state', 'requiring pressurized location', and 'suitable for an unpressurized location'. Further, the efficiency of arrangements of experiments within the volume available is a major factor in determining the number of experiments that can be accommodated in a given volume. Experiment work area, aisles, etc., must be deducted from the gross volume available. Volumes available for experiment installation on various spacecraft, including one compartment of the modular configurations, are given in Fig. 5-9 along with tabular volume requirements of the AES flights. 'Tabular' as used here means the arithmetic sum of the individual experiment volumes in an undeployed or stowed condition.

The inability of a three-man crew to perform the AES Priority I experiments with the original (March 15, 1965) man-hour requirements has been shown in Fig. 5-5. A further breakdown of these requirements is shown in Fig. 5-10. A re-evaluation of these experiment manhour requirements will be required to achieve mission compatibility or it will be necessary to delete certain experiments from the current AES flight schedule.

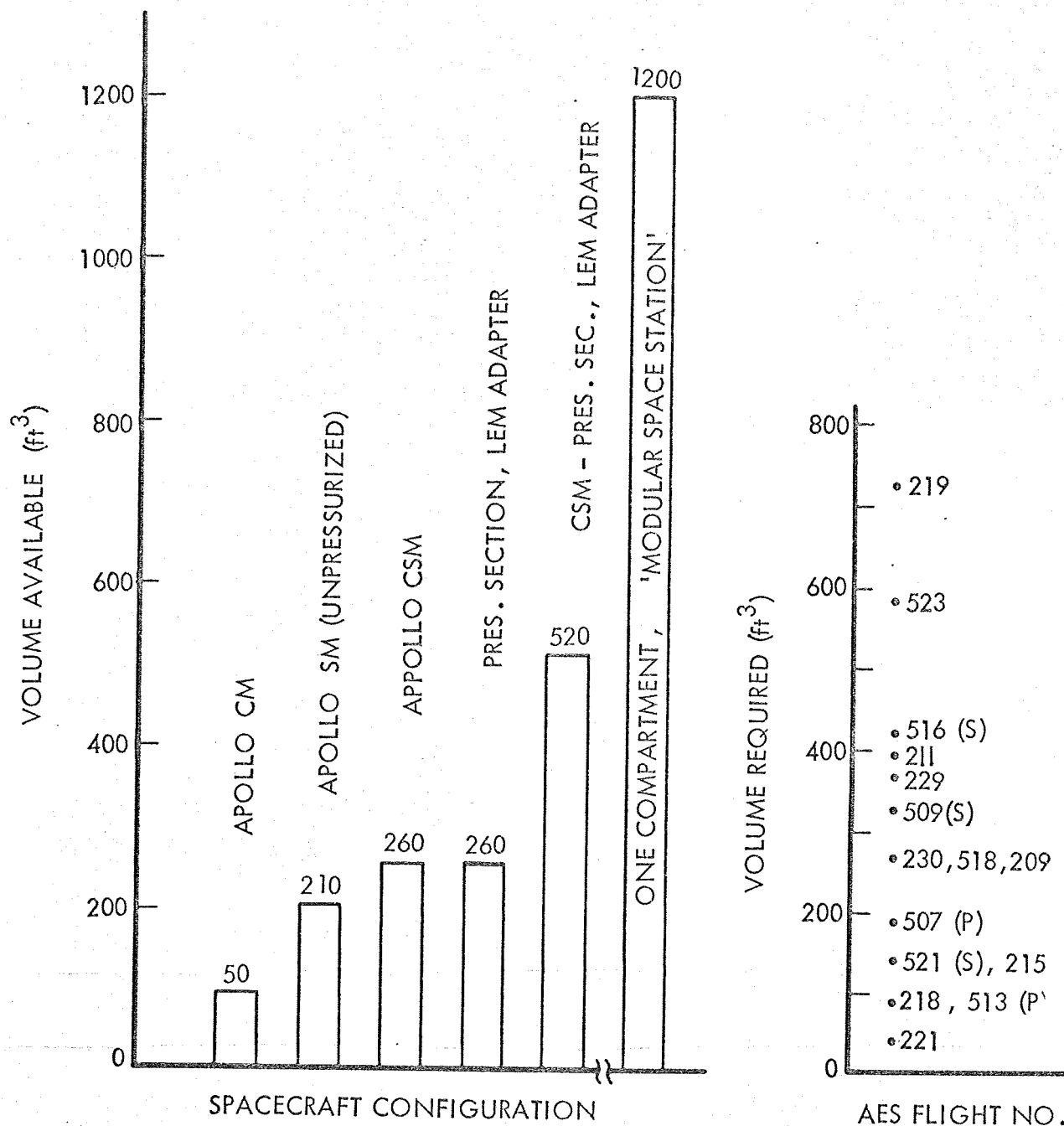


FIG. 5-9 TABULAR VOLUME OF EXPERIMENTAL EQUIPMENT FOR 15 AES FLIGHTS COMPARED TO VOLUMES AVAILABLE IN VARIOUS SPACECRAFT CONFIGURATIONS

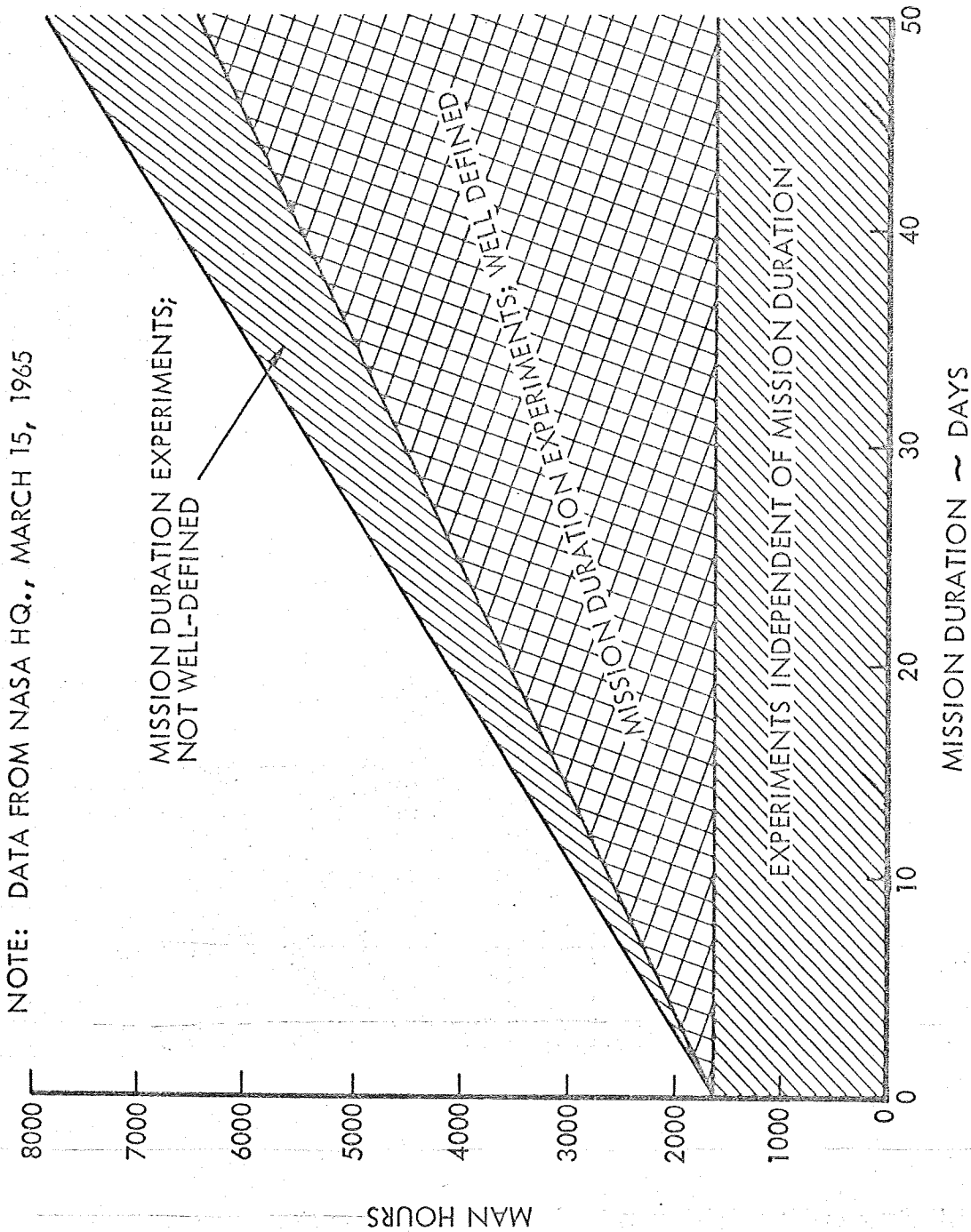


FIG. 5-10 ESTIMATE OF MANHOURS REQUIRED TO PERFORM THE 85 PRIORITY 1 AES EXPERIMENTS

Experiments in the medical and behavior categories total 24 out of the 85 AES Priority I experiments. The effect of summarizing these two categories separately is illustrated in Table 5-2. The medical and behavior category experiments are seen to have small weight, volume, and manhour requirements but the physical science (non-medical/behavior) experiments are achieved at a relatively high penalty.

Insufficient depth of analysis of the AES experiments has resulted in a broad spread of estimates of experiment requirements. Trends have begun to appear, however, and the preliminary analyses to date indicate that some regrouping of the planned experiments will be required.

One-Compartment Dependent Laboratory with AES Experiments

Figure 5-11 shows the interior arrangement of a single compartment laboratory that incorporates the experimental equipment included in Flights 218 and 219 as shown in Table 5-1. However, the 400 series of biological experiments were omitted due to the large volume requirements of the life support equipment for animals. The above two AES flights were to be consecutive flights with one astronaut staying aloft for a full 90-day period. This interior arrangement shows that the majority of experiments can be performed in a One Compartment Laboratory with only resupply of consumables and crew being required.

The lower portion of the compartment is free of structure and equipment so that a centrifuge may be located and operated there. The centrifuge is supported from rings located around the centerline access opening and is stabilized by wheels that run in a track at the periphery.

Power for operation is applied to these wheels. Centrifuge control is maintained by a crew member in the center of the compartment.

Section A-A shows a personnel airlock with a docking hatch at the end. This airlock is retracted within the compartment during launch. The control console and human performance test area is on the right side while the left side of this section shows an area for pressure suit storage.

Table 5-2

SUMMARY WEIGHT AND VOLUME DATA ON AES PRIORITY I EXPERIMENTS

Mission	FLIGHT NO.	TOTAL EXPERIMENTS		TOTAL NO. EXP'S	TOTAL NON-MEDICAL/BEHAVIOR EXPERIMENTS			AVERAGE WEIGHT		AVERAGE VOLUME	
		WEIGHT (lb)	VOLUME (ft ³)		NUMBER	WEIGHT	VOLUME	TOTAL EXP'S	NON MEDICAL/BEHAVIOR	TOTAL EXP'S	NON MEDICAL/BEHAVIOR
28.5°	230	3152	268	44	3	2381	233	72	794	6	65
28.5°	229	3196	384	47	6	2425	349	65	404	8	51
28.5°	523	7754	546	44	23	6983	506	176	304	13	22
S	521	8823	142 ⁽¹⁾	49	8	2052	107	58	257	3	9
+83°	518	4485	265	50	9	3714	230	90	413	5	21
S	516	6486	424	56	15	5715	389	116	381	8	23
28.5°	221	1331	44	43	2	560	9	31	280	1	5
28.5°	219	4399	727	49	8	3628	692	90	453	15	81
28.5°	218	1173	89	56	15	402	54	21	268	2	1
-81.5°	513	1771	86	50	9	1000	51	35	111	2	1
28.5°	215	3067	148	46	5	2296	113	67	458	3	15
S	509	3145	326	50	9	2374	291	63	264	7	28
+90°	507	3214	195	47	6	2443	160	68	407	4	20
28.5°	211	1216	404	45	4	445	369	27	111	9	80
28.5°	209	2566	276	46	5	1795	241	56	359	6	40

Total Weight = 29,624 lb

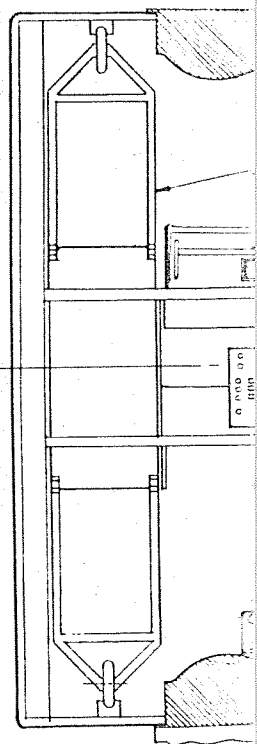
Total Volume = 4,749 ft³ includes 2300 ft³ (Experiment No. 1406)
(Flight 521)

Total Less Medical & Behavior* = 28,853 lb
4,714 ft³

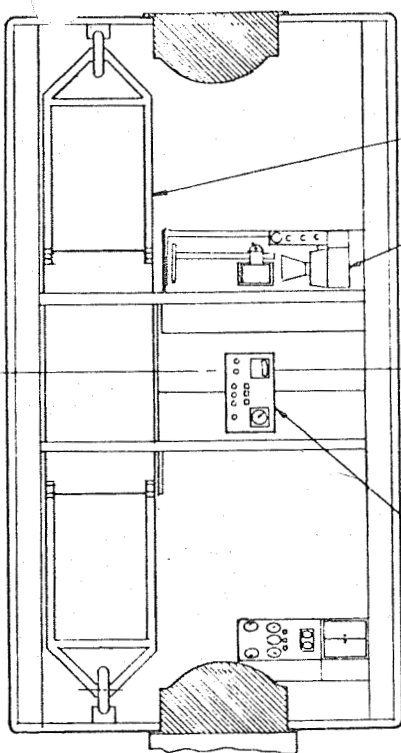
*Medical (21 Experiments) and Behavior (3 Experiments subdivided
in 20 parts): total 771 lb and 35 ft³

(1) Does not include 2300 ft³ of Experiment No. 1406 (optical telescope)

FIG. 2-59



SECTION D



SECTION D-D

SPACE-SUIT STORAGE

CURTAIN

CENTRIFUGE
STRUCTURE

PORTABLE X-RAY STOWED

MICRO-CHEM
CONSOLE

CENTRIFUGE
CONTROL PANEL

STOWAGE OF EQUIPMENT
FOR CAPILLARITY STUDIES,
LIQUID DROP DYNAMICS,
VAPOR/GAS DYNAMICS, &
ZERO-G HEAT TRANSFER

CENTRIFUGE GONDOLA

MASS

PLAN VIEW

C

B

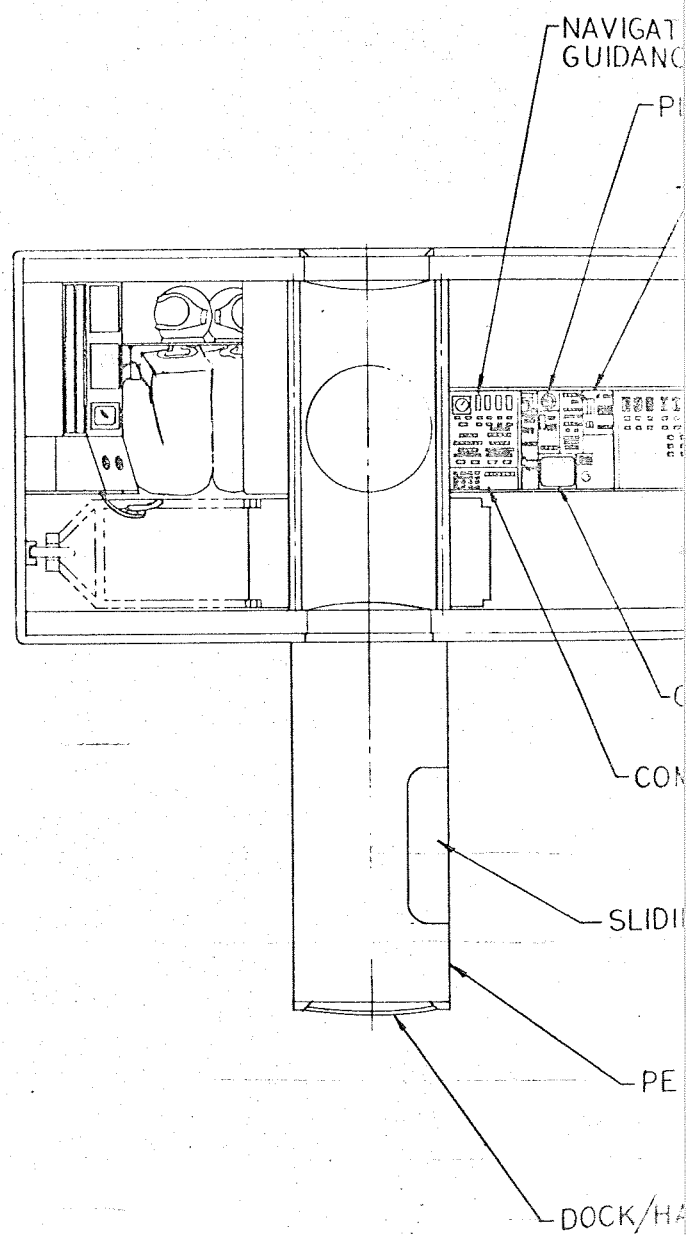
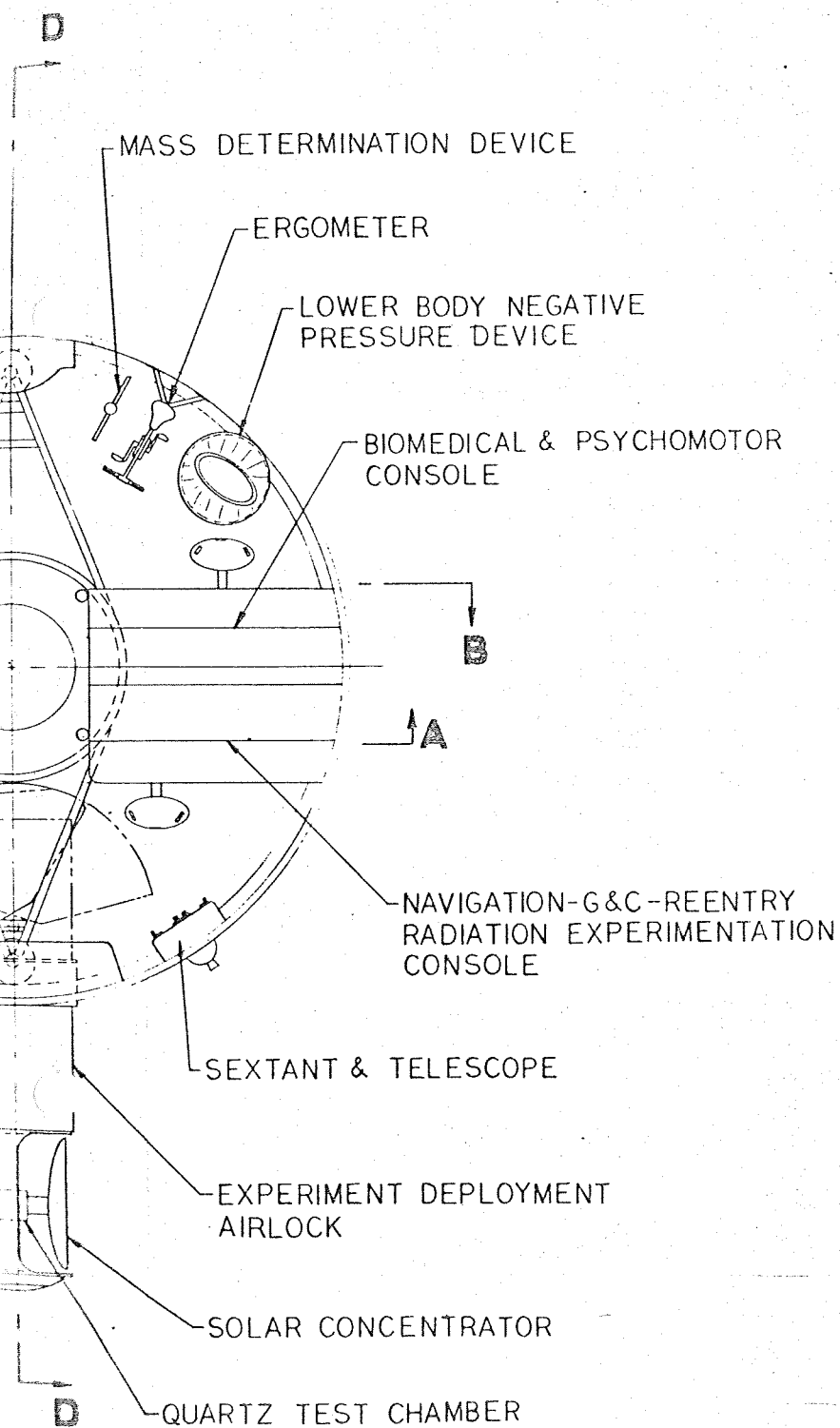
A

C

D

D

C



SECTION A-A

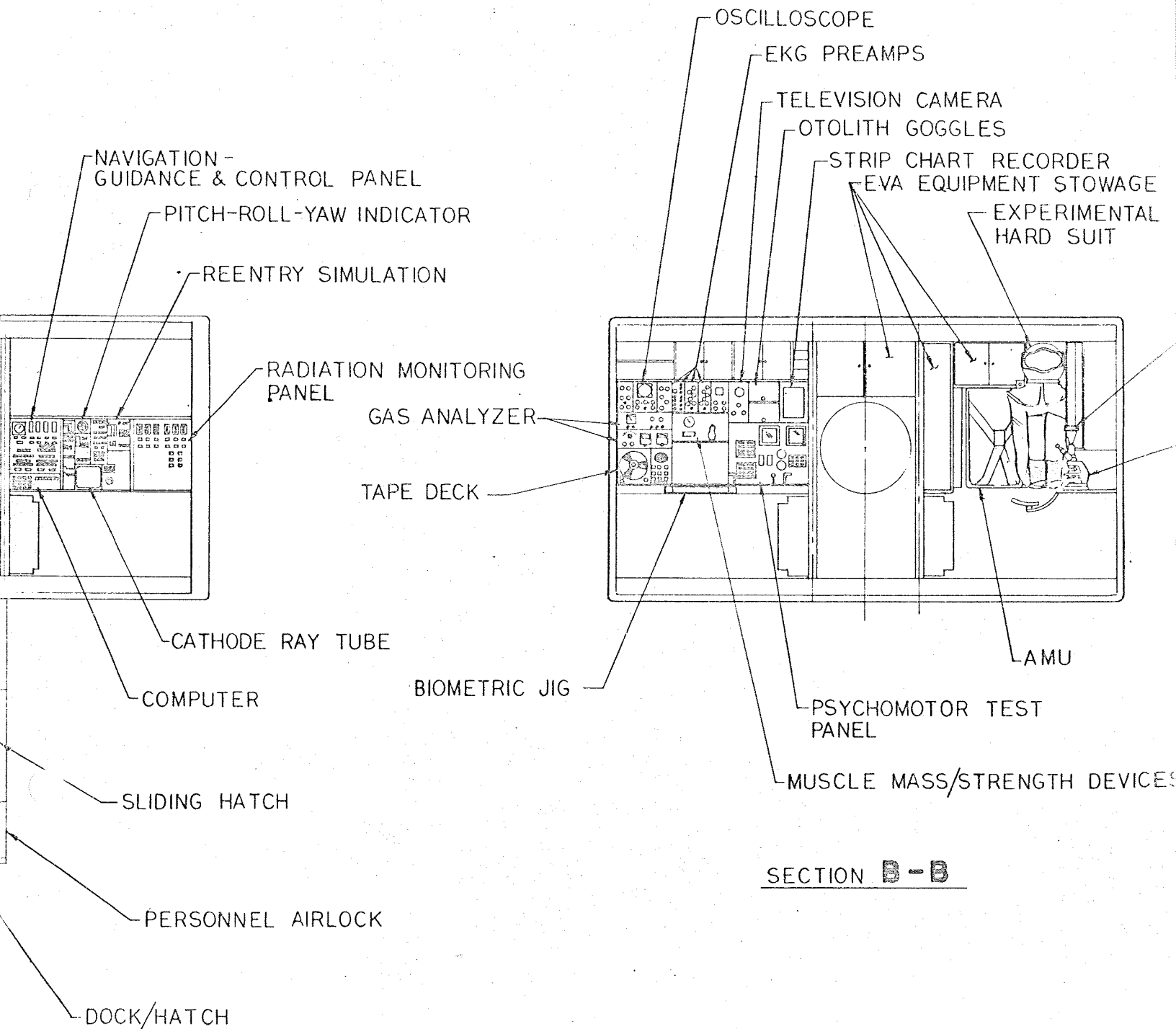
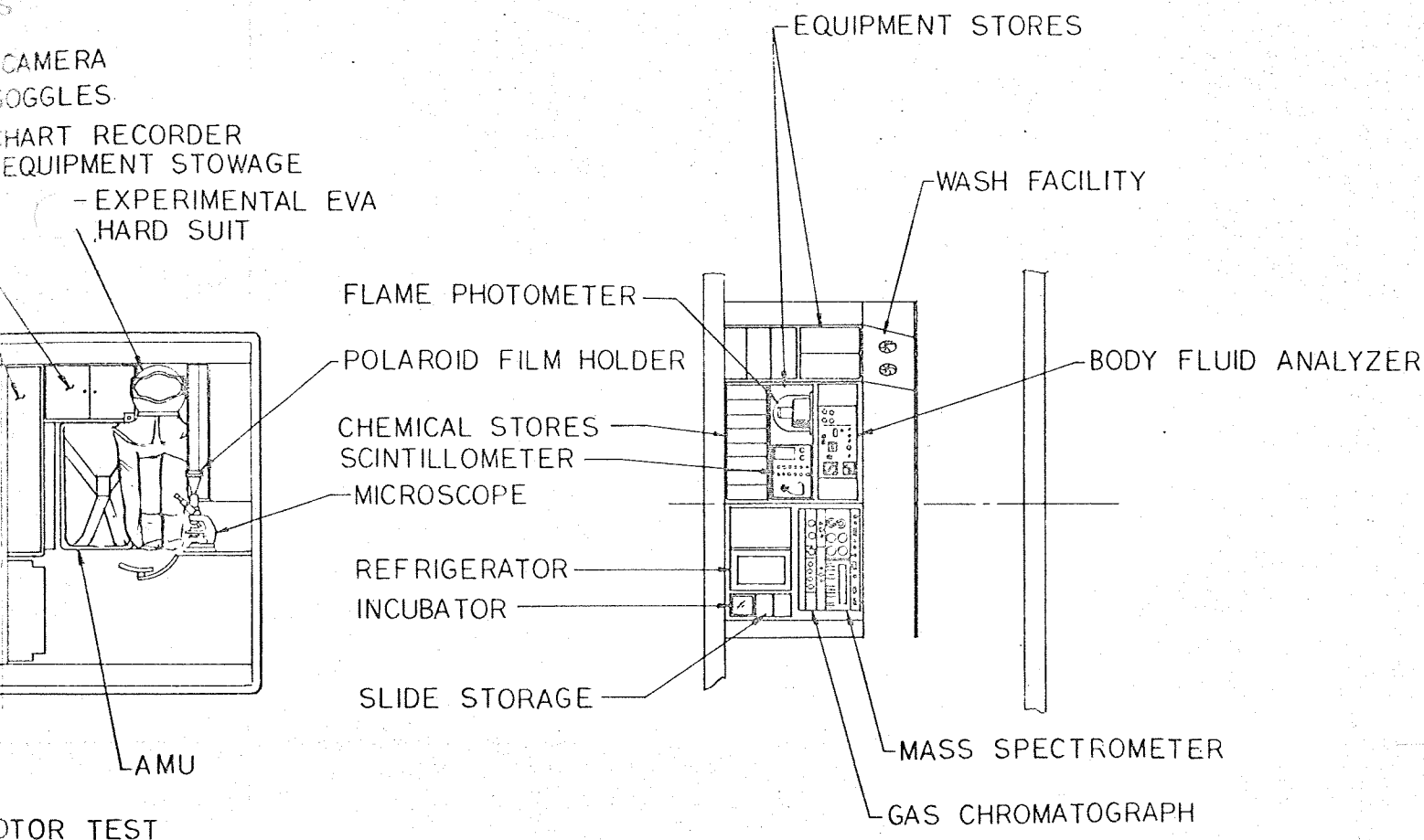


FIG. 5-11 ONE-COMPARTMENT DEPENDENT LABORATORY WITH AES EX
EQUIPMENT FOR FLIGHTS 218 AND 219



SECTION C-C

SS/STRENGTH DEVICES

B

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Section B-B on the right side of this figure shows the extravehicular suit and maneuvering unit. To the left of the centerline is shown the biomedical and psychomotor console. The biomedical equipment is patterned after that recommended by Lockheed Missiles and Space Company on Contract NASw-1071, Biological Measurement of Man in Space.

The plan view shows some experiments that do not appear in the sectional views. Among these are the mass determination device, the ergometer, and the lower body negative pressure device. One of the universal hatches has an experiment deployment airlock. In it is shown a solar concentrator that is used for melting samples of materials. This unit is also retracted during launch.

Section C-C shows the microchemical console, and the stowed position of the portable x-ray equipment can be seen in Section D-D.

AES Flight 523 is a low-altitude, low-inclination flight of 45 days duration with flights 229 and 230 as resupply flights. It is possible to combine these experiments into one flight of a One-Compartment Laboratory with one or two resupply flights for crew and consumables, depending upon the total duration desired for some of the continuous experiments. Figure 5-12 shows the interior arrangement for the One-Compartment Laboratory incorporating the experiments of Flights 523, 229, and 230. This combined flight includes all of the experiments of the previously combined Flights 218 and 219 (Fig. 5-11) except for the extra-vehicular operations and the artificial g experiment using the centrifuge. The removal of the centrifuge makes one-third of the compartment available for other experiments. Once again, the 400 series biological experiments were omitted due to the large volume requirements of the life support equipment for the animals. The general floor arrangement of the compartment is shown in the plan view of Fig. 5-12. The biomedical and psychomotor console, the navigation and the radiation console, and the experiment deployment airlock

along with the ergometer and lower body pressure device are all located as shown previously in Fig. 5-11. Relocation of the microchemical console, which is retained as a unit, permits the addition of a toilet, portable shower stall and other personal hygiene equipment at the left of the plan view of Fig. 5-12. Cabin atmosphere monitor and control equipment are located adjacent.

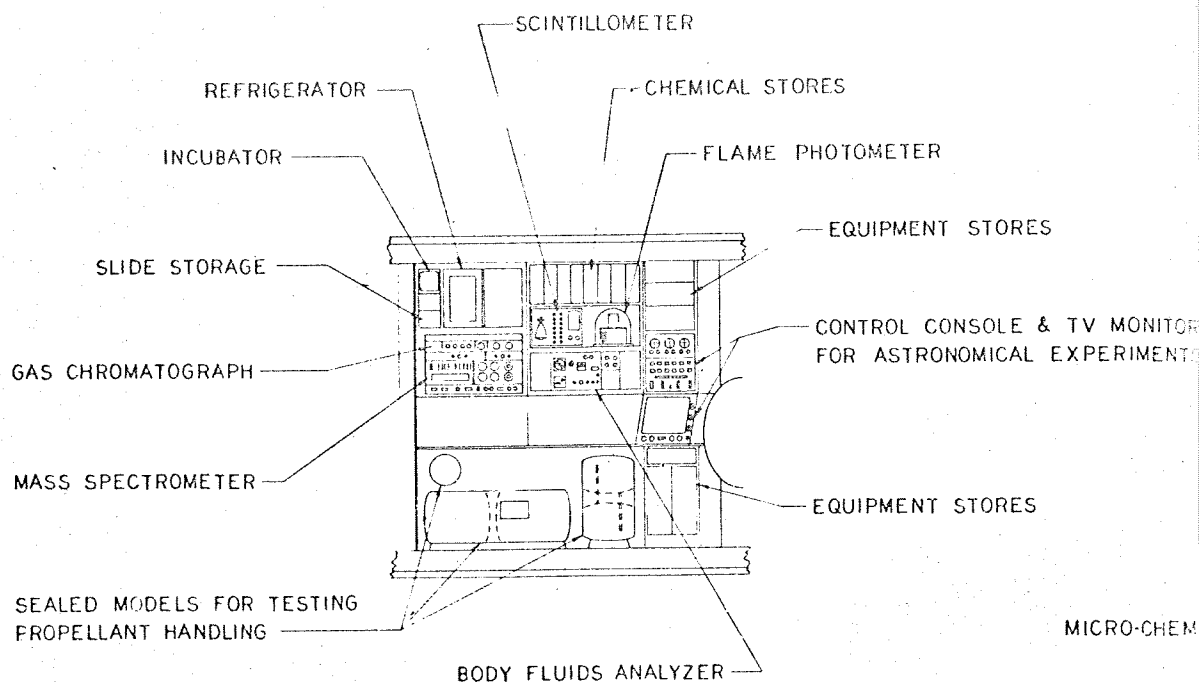
The control console and human performance testing are shown to the right in View A-A of Fig. 5-12. Above this is the food storage and preparation area. Covers similar to window shades can be stretched over the control console during food preparation if desired. Additional equipment stowage is located beneath the consoles with accessibility from either side. Storage for personal hygiene equipment is shown at the left side of this view with the microchemical console in the background.

View B-B shows the biomedical and psychomotor console at the left. The urine accumulator tank and processed fecal storage is shown to the right above the toilet. Stowage for liquid/gas/solids behavior tests is shown in the background, right of center.

The microchemical console is shown in detail in View C-C and is the same as used for flights 218 and 219. At the right side of the microchemical console, a control console and a TV monitor have been added for the astronomical experiments. Sealed models for testing propellant handling are shown beneath the microchemical console.

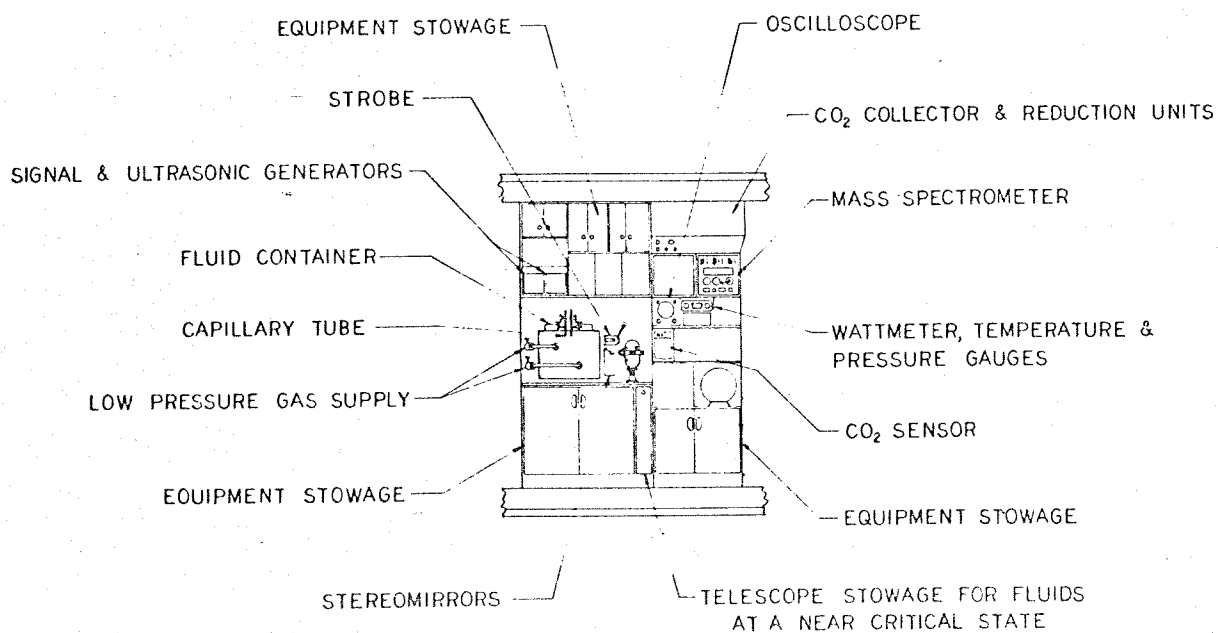
View D-D shows the equipment for monitoring and controlling the cabin atmosphere. The test set-up shown is for liquid drop dynamics. Stowage is indicated for the additional equipment required for the 600 series tests on liquid/gas/solids behavior.

The 40-inch MORL type telescope is shown in its operational position attached to a docking port. The telescope would be mounted on the top of the compartment during launch along with the other exterior equipment required for the astronomical observations of the 700 series experiments. The space structures equipment for the 1300 series

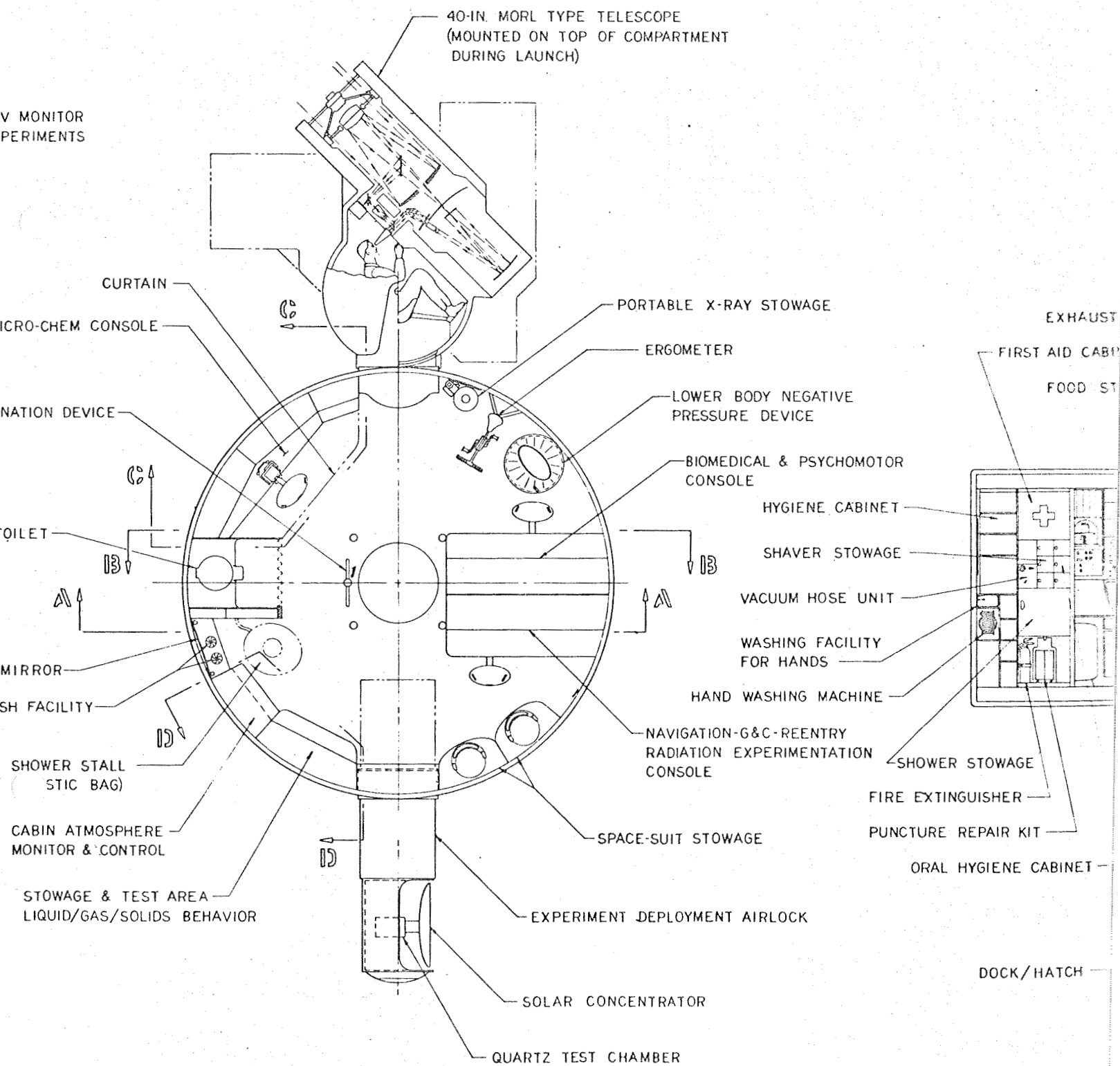


VIEW C-C

MASS DETERMINATION DE



VIEW D-D



PLAN VIEW

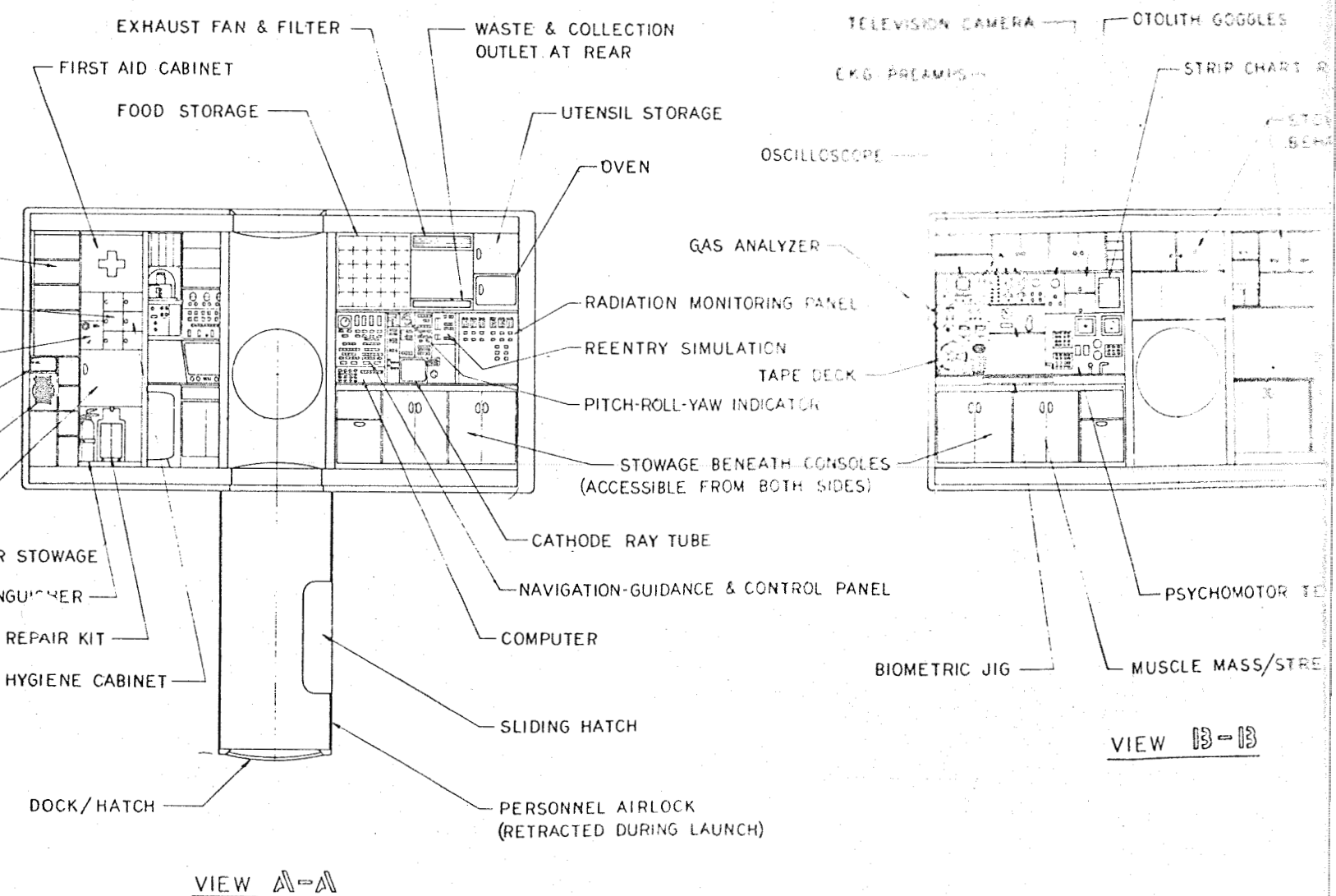


FIG. 5-12 ONE-COMPONENT DEPENDENT LABORATORY WITH AEROSOL EQUIPMENT FOR FLIGHTS 523, 229, AND 230

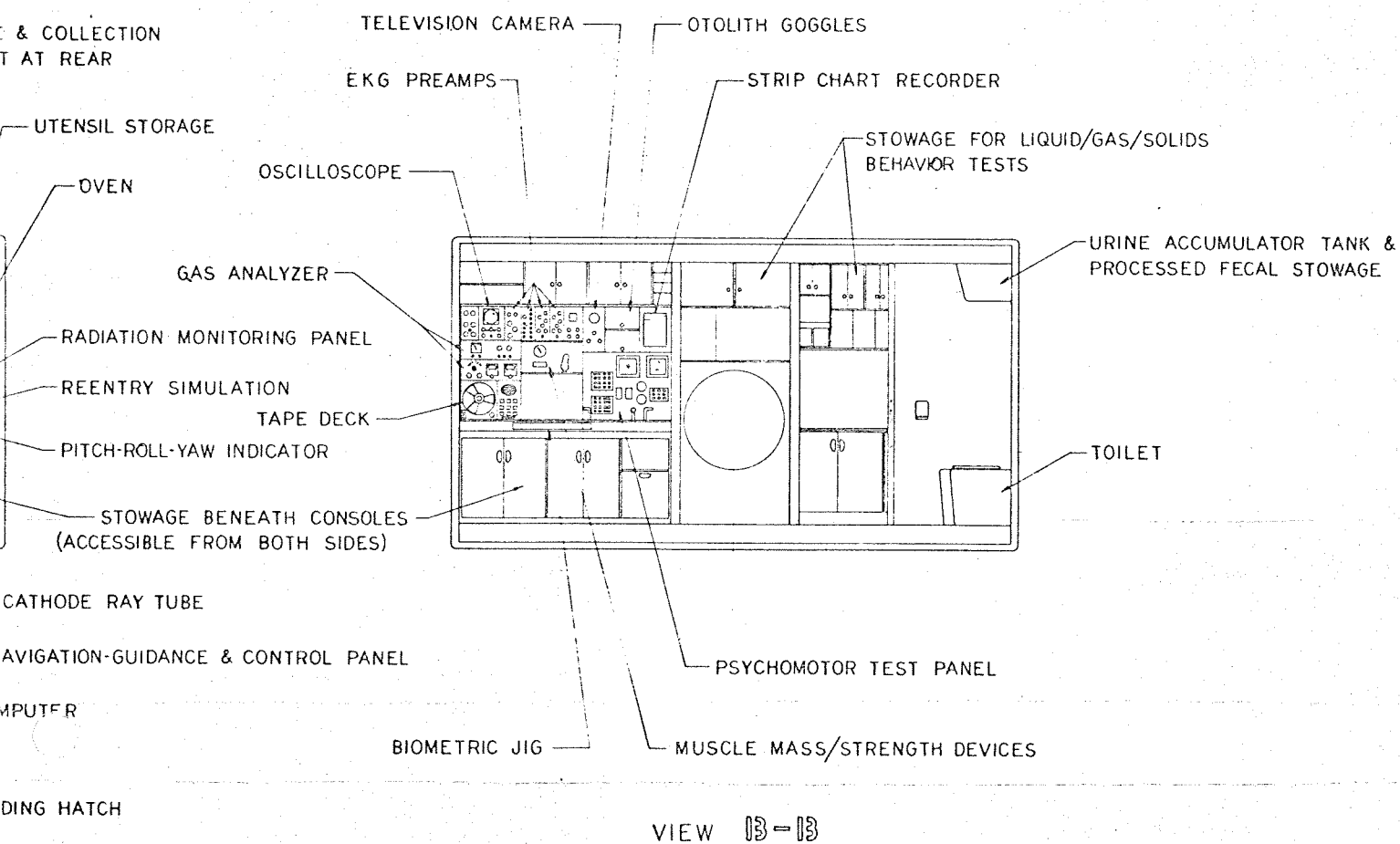


FIG. 5-12 ONE-COMPONENT DEPENDENT LABORATORY WITH AES EXPERIMENTAL EQUIPMENT FOR FLIGHTS 523, 229, AND 230

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experiments would likewise be mounted (not shown) outside on the top of the compartment.

REFERENCES (Section 5.1)

1. Apollo Extension Systems - 1300 Cubic Foot Laboratory, Conf., The Boeing Co., (17 Volumes).
2. Apollo Extension System Earth Orbit Mission Study, Final Report, 10 May 1965, Conf., Grumman Aircraft Engineering Corp. (5 Volumes)
3. Extended Apollo Systems Utilization Study, 5 May 1965, Conf., North American Aviation, S & IS Division, (5 Volumes).

5.2 SUPPLEMENTARY APPLICATIONS

From an extensive list of potential experiments and surveys, the NASA Manned Spacecraft Center has selected a group to serve as a mission model for manned space stations. The titles of these 648 selected applications were published in the document, "National Multipurpose Space Station Utilization Outline," dated Oct. 1, 1964. This list categorized the experiments and applications into five broad areas:

- Basic Science and Technology Research
- Earth Orbital Engineering Development and Qualification
- Earth Orbital Functional Applications
- Space Mission Support
- National Defense Support

From these categories NASA selected 301 experiments and defined them in sufficient depth to identify the following items:

- Experiment description and objectives
- Power, weight, and volume requirements for experimental apparatus
- Crew time necessary to carry out the experiment or survey
- Crew skill type required
- Total experiment time
- Experiment priority

In addition, Lockheed selected 104 additional experiments from the Utilization Outline and completed descriptions for these, making a total of 405 that were processed.

Table 5-3 summarizes by category the number of applications listed in the Utilization Outline and the number actually processed. The processing consisted of defining the experiments in greater depth to assess their impact on the modularized space station design, operation, and utilization. To aid in formalizing these constraints and requirements, a standardized Experiment and Application Summary form, as shown in

Fig. 5-13, was prepared. In addition, where possible, pictures or schematic diagrams were included to illustrate any unique test equipment involved. The complete set of 405 Experiment and Application Summaries are presented in the Appendix volume of this report.

These experiment summaries served several purposes:

1. Experiment interdependencies were established in several ways. One grouping was based on experimental equipment commonality. Insofar as possible, those experiments using common test equipment were grouped in close proximity in both space and time; that is, they would tend to be placed near each other in the space station laboratory compartments, and, when required, would be performed at nearly the same time. This was especially true for several of the biomedical experiments and for many of the Earth survey applications, as shown in Tables 5-4 through 5-8.

Another aspect of interdependence grouping consisted of determining which experiments should precede others in time. This is necessary where the results of one or more tests must be obtained before others can be carried out. Because of a NASA-directed shift of emphasis, this type of interdependence grouping was done only for those experiments received before the mid-term of the study. The result of this grouping is shown in Table 5-9.

Several of the biomedical experiments were grouped in sets for convenience in gathering data. For example, those tests comprising a general physical examination were grouped together and would be carried out as a group (Table 5-10).

2. The experiment briefs aided the spacecraft designers in laying out the inboard profiles. The briefs describe the necessary test apparatus by such items as: critical dimensions, volume, suggested placing of equipment, pictures or diagrams of existing apparatus, and potential safety hazards.
3. Subsystem designers were alerted to special requirements placed on the space station, such as heating or cooling of equipment, unusual spacecraft stability specifications, or stringent navigation requirements.
4. Space station operating parameters were affected by several items described in the briefs. Certain experiment performance requirements can be satisfied only by special polar and synchronous missions, or by rotating or non-rotating stations. The number of experiments falling into these categories are listed in Table 5-11.

Table 5-3
SPACE STATION APPLICATIONS SUMMARY

<u>Category</u>	<u>Suggested Number of Applications</u>	<u>Number of Applications Processed</u>
BASIC SCIENCES AND TECHNOLOGY RESEARCH		
Life Science	161	152
Space Environment	28	17
Astronomy/Geoscience	71	30
Physics/Chemistry	72	18
EARTH ORBITAL ENGINEERING DEVELOPMENT AND QUALIFICATION		
Crew Systems	25	23
Structures and Materials	50	39
Electric Systems/Mechanical Systems	31	19
Navigation-Guidance/Communications	37	13
Optical Systems	5	2
Propulsion	18	8
Stability and Control	14	13
Space Maint./Operational Procedures	34	11
EARTH ORIENTED FUNCTIONAL APPLICATIONS		
Meteorology	19	7
Communications/Navigation Aid	10	8
Surveys of Earth/Socio-Economic Studies	36	28
SPACE MISSION SUPPORT		
Service and Maintenance	3	2
Crew Mission Criteria	4	2
Orbital Launch Operations	7	2
Mission Control	8	6
Orbital Recovery Operations	6	4
NATIONAL DEFENSE SUPPORT		
Passive Support	4	1
Active Support	5	
TOTAL	648	405

Table 5-4
BIOMEDICAL EXPERIMENTS USING CALSUL EQUIPMENT

<u>Number</u>	<u>Title</u>
1.1.1.6	Venous Pressure and Circulation Time
1.1.1.11	Blood Catecholamine
1.1.1.32	Urine 17 kg Steroid
1.1.1.44	Blood and Urine Sugar
1.1.1.53	Blood 17 kg Steroid
1.1.1.61	Glomerular Filtration Test
1.1.1.62	Blood Alkaline Phosphate
1.1.1.71	Blood-Urea Nitrogen
1.1.1.75	Urinary Albumin
1.1.1.78	Blood ATP
1.1.1.80	Urine Catecholamine
1.1.1.88	Blood and Urine Creatinine

Table 5-5
EXPERIMENTS USING X-RAY EQUIPMENT

<u>Number</u>	<u>Title</u>
1.1.1.1	Pulmonary Pathology and Heart Size
1.1.1.14	Kidney and Bladder Stone Formation
1.1.1.30	Gastrointestinal Tract Motility
1.1.1.87	Bone Density

Table 5-6
EXPERIMENTS USING HUMAN CENTRIFUGE

<u>Number</u>	<u>Title</u>
1.1.1.4	Body Mass
1.1.1.90	Centrifuge Test

Table 5-7
EXPERIMENTS USING MAPPING CAMERA AND ASSOCIATED EQUIPMENT

<u>Number</u>	<u>Title</u>
1.4.1.10	Geographic Studies
3.4.1.1	Survey and Dynamic Mapping of the Earth's Surface for Agricultural Production Estimates
3.4.1.2	Water Resources Survey
3.4.1.5	Forestry Survey
3.4.1.6	Agricultural Survey
3.4.1.8	Crop Prediction
3.4.1.9	Monitor Earth's Vegetation
3.4.1.10	Optimum Use of Habitable Land
3.4.1.11	Mineral Survey
3.4.1.12	Observation of Volcanic Eruption Effects
3.4.2.1	Oceanography Studies
3.4.2.6	Tidal Wave Warning

Table 5-8

EXPERIMENTS USING INFRARED RECEIVER AND ASSOCIATED EQUIPMENT

<u>Number</u>	<u>Title</u>
1.4.1.4	Infrared (7-30 microns) Response of Geologic Materials
3.4.1.1	Survey and Dynamic Mapping of the Earth's Surface for Agricultural Production Estimates
3.4.1.2	Water Resources Survey
3.4.1.5	Forestry Survey
3.4.1.6	Agricultural Survey
3.4.1.7	Forest Fire Warning
3.4.1.8	Crop Prediction
3.4.1.9	Monitor Earth's Vegetation
3.4.1.10	Optimum Use of Habitable Land
3.4.1.11	Mineral Survey
3.4.1.12	Observation of Volcanic Eruption Effects
3.4.1.14	Determine Composition of Soils from Spectral Infrared Emission
3.4.1.15	Determination of Composition and Distribution of Soil Types from Infrared Emission Imagery
3.4.1.16	Atmospheric Modification of the Infrared Spectral Reflectance and Emittance from Vegetation
3.4.2.1	Oceanography Studies
3.4.2.3	Sea Temperature Gradients
3.4.2.7	Iceberg Position Status
3.4.2.9	Fish Migration
3.4.2.12	Thermal Structure and Patterns of the Ocean Surface from Spectral Infrared Emittance
3.4.2.13	Determination of the Thermal Pattern and Structure of the Ocean Surface by Imaging the Emitted Infrared Radiation

Table 5-9
SEQUENTIAL INTERDEPENDENCE OF EXPERIMENTS

<u>Primary Number</u>	<u>Experiment Title</u>	<u>Dependent Number</u>	<u>Experiment Title</u>
2.1.2.8	Fire Extinguishment Under Zero or Partial Gravity Conditions	1.6.2.1	Combustion of Materials in Zero-g
2.9.1.11	Evaluation of Stabilization Systems for Laser Communication	2.6.1.3	Laser Communication Experiment
2.6.1.6	Deployment and Erection of Large Antennas	2.6.1.2	Free Space Antenna Pattern Determination
2.11.3.1	Crew Extra-Vehicular Suit and Portable Life Support System Training	2.10.2.1	Repair of Thermal Control Surfaces in Space
		2.10.2.2	Study of Space Maintenance Methods and Tools
		3.1.1.4	Meteorological Satellite Support
		4.4.1.3	Communication Satellite Support
		4.4.2.1	Navigational Satellite Support
2.9.2.4	Techniques for Trailing Test Units from Space Station	1.2.4.1	Ultra-High Vacuum Research
		2.6.1.1	Passive Communication Relay Development

Table 5-9

SEQUENTIAL INTERDEPENDENCE OF EXPERIMENTS (Cont.)

<u>Primary Number</u>	<u>Experiment Title</u>	<u>Dependent Number</u>	<u>Experiment Title</u>
2.9.1.5	Evaluation of Earth, Moon, Sun and Star Tracker Performance	1.2.1.1	Extraterrestrial Electromagnetic Radiation Survey
		1.2.1.7	Albedo Level Measurement Program
		1.2.4.2	Horizon Spectrometry
		1.4.1.1	Multispectral Sensing of the Terrestrial Surface
		2.7.2.1	Advanced Photographic Systems Evaluation
2.9.1.3	Evaluation of Lock-On Systems for Terrain Reconnaissance and Communication	1.4.1.2	Photography of the Terrestrial Surface
		3.1.1.1	Mapping of Cloud Formations
		3.1.1.2	Mapping of Changes in Snow and Ice Coverage

Table 5-10
EXPERIMENTS PERFORMED WITH THE GENERAL PHYSICAL EXAMINATION

<u>Number</u>	<u>Title</u>
1.1.1.2	Evaluation of Superficial Sensation
1.1.1.3	Blood Volume
1.1.1.7	Exercise Test
1.1.1.10	Muscle Function
1.1.1.17	Capillary Fragility
1.1.1.18	Visual Fields Evaluation
1.1.1.19	Incisional Healing and Bleeding Time
1.1.1.20	Respiratory Rate
1.1.1.21	Mucosal Integrity Evaluation
1.1.1.23	Skin Thickness
1.1.1.24	Venous Distension
1.1.1.27	Body Temperature
1.1.1.31	Color Vision Evaluation
1.1.1.33	Heart Sounds
1.1.1.34	Muscle Size
1.1.1.36	Reflex Response and Clonus Evaluation
1.1.1.38	Vestibular Reaction
1.1.1.41	Pulse Rate
1.1.1.45	Visual Acuity, Depth Perception and Accomodation
1.1.1.58	Incidence of Aerotitis Media
1.1.1.59	Expiratory-Inspiratory Force
1.1.1.66	Blood Pressure
1.1.1.74	Joint Motion Range
1.1.1.79	Retinal Examination
1.1.1.82	Liver Size
1.1.1.86	General Physical Examination

Table 5-11
NUMBER OF EXPERIMENTS REQUIRING SPECIAL ORBITS
OR GRAVITY CONDITIONS

	<u>Polar Orbit</u>	<u>Synchronous Orbit</u>	<u>No Orbit Requirements</u>
Number of Candidate Experiments	87	56	352
Number Requiring Special Orbits	0	9	--
Number Greatly Benefiting from Special Orbit	40	4	--
	<u>Zero g</u>	<u>Both Zero and Partial g</u>	<u>No Special Requirements</u>
Number of Experiments	217	143 Desirable 13 Required	173

5. From the summaries, key punch inputs for the Development of Events Sequences (DOES) computer program were prepared. This computer program is described in Section 5.3. The IBM cards were coded for the following items: experiment number, priority, crew skill, crew time, electrical power, and experiment interdependency.
6. Because of various constraints, not all experiments can be or should be performed on all the space stations. From the Experiment Summaries, a potential experiment assignment was compiled as shown in Table A-1, of the Appendix. This list would allow a DOES IBM card deck to be compiled for each of the space station configurations; however, the NASA-directed shift of emphasis precluded this final filtering by the DOES program.
7. Finally, from the Experiment and Application Summaries, histograms and their associated cumulative distribution functions were constructed for the following parameters: weight, stored volume, manpower requirements, and electrical power requirements. Figures 5-14 through 5-21 present these curves.

Figure 5-14 shows the distribution of test equipment weight required for each experiment or application. This is a highly skewed distribution, peaking between 0 and 50 pounds. It should be noted also that there are several experiments requiring very heavy test equipment; five requiring weights between 1000 and 2000 lb, two between 5000 and 10,000 lb, and one at 48,000 lb. Figure 5-15 is the derived cumulative distribution of test equipment weight. The mean value was calculated to be 270 lb per experiment with 90 percent of the experiments requiring 225 lb per experiment or less.

Figure 5-16 presents the distribution of test equipment stored volume requirements for each experiment. This is also a highly skewed distribution, peaking between 0 and 5 cu ft per experiment with a few experiments having a very high volume requirement. Figure 5-17 is the volume requirement cumulative function. The mean value is 13 cu ft per experiment and 90 percent of the tests require less than 7.5 cu ft each.

Figures 5-18 and 5-19 are the frequency distribution and the cumulative distribution, respectively, for electrical power. The mean value was calculated to be 0.21 kw per experiment, and up to the 90th percentile the experiments required 0.4 kw per experiment or less.

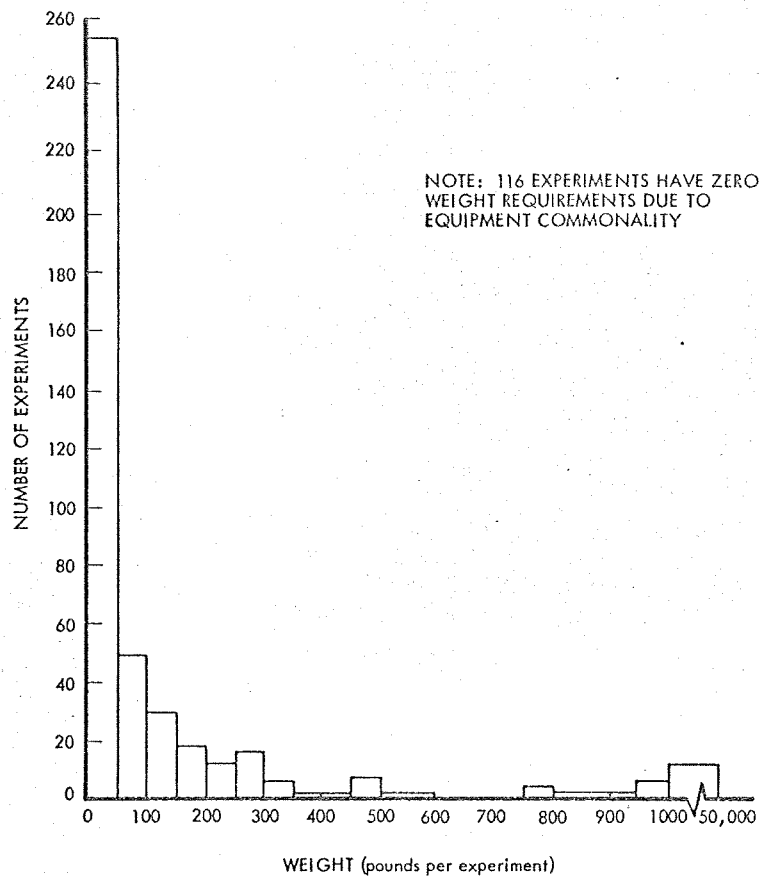


FIG. 5-14 DISTRIBUTION OF EXPERIMENT WEIGHTS

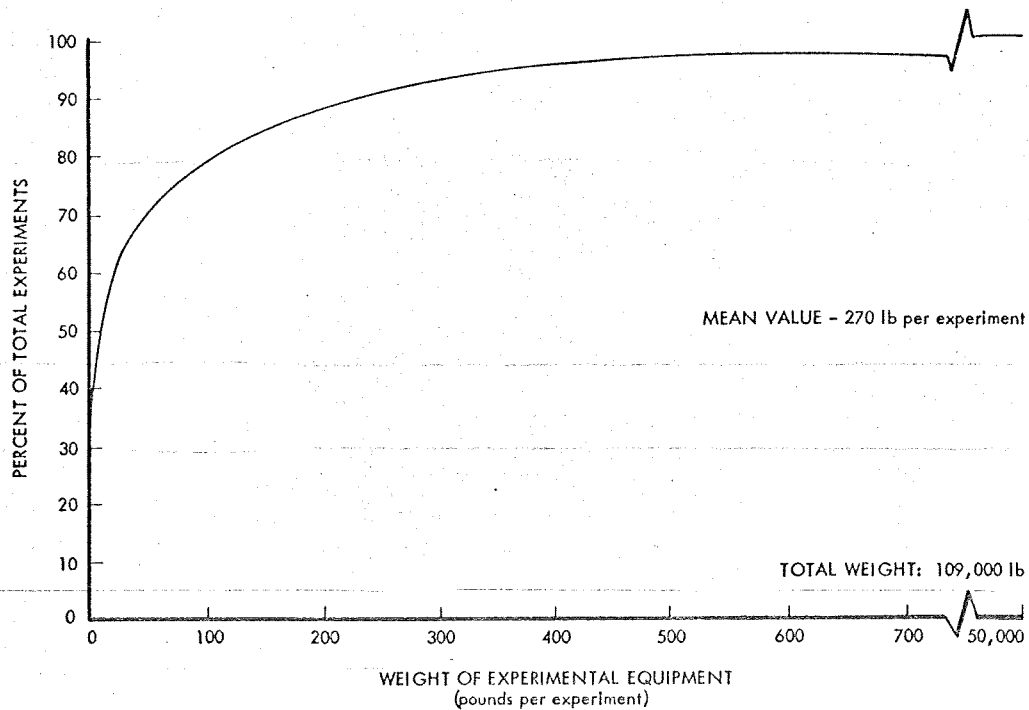


FIG. 5-15 CUMULATIVE DISTRIBUTION OF WEIGHT FOR EXPERIMENTAL EQUIPMENT

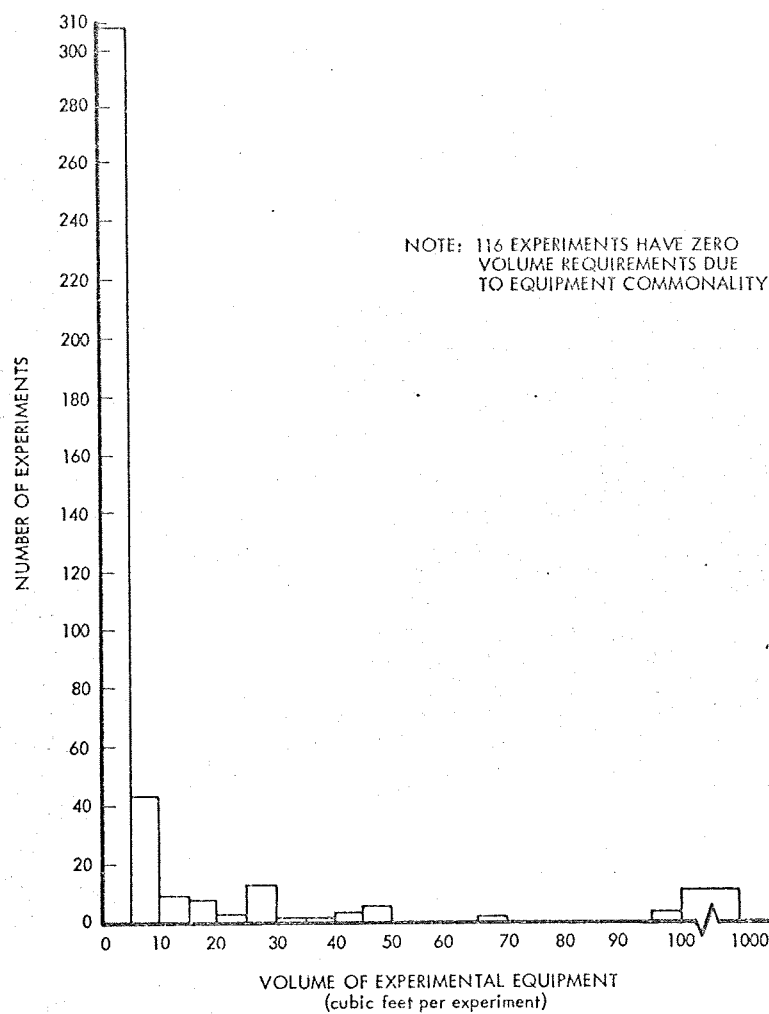


FIG. 5-16 DISTRIBUTION OF EXPERIMENT VOLUME REQUIREMENTS

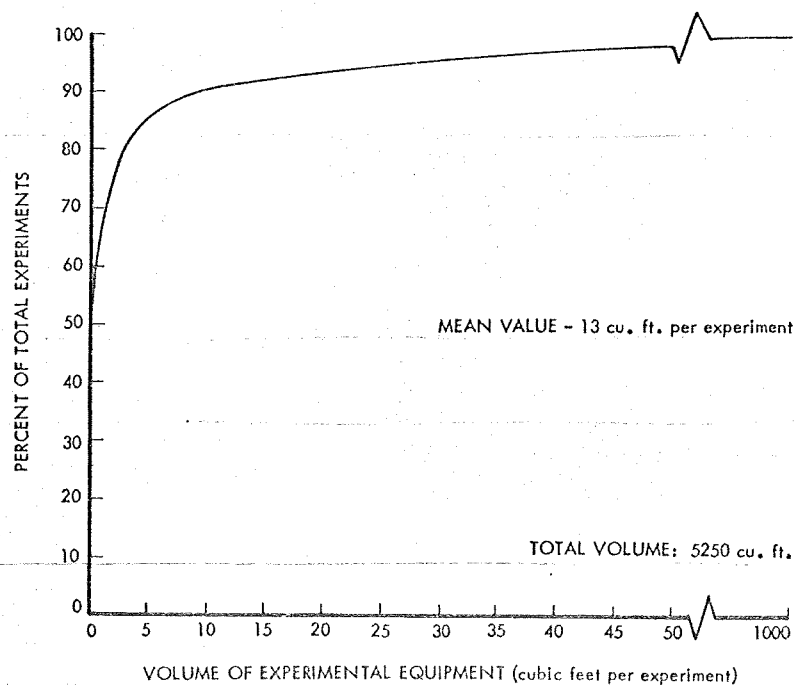


FIG. 5-17 CUMULATIVE DISTRIBUTION OF VOLUME REQUIREMENTS FOR EXPERIMENTAL EQUIPMENT

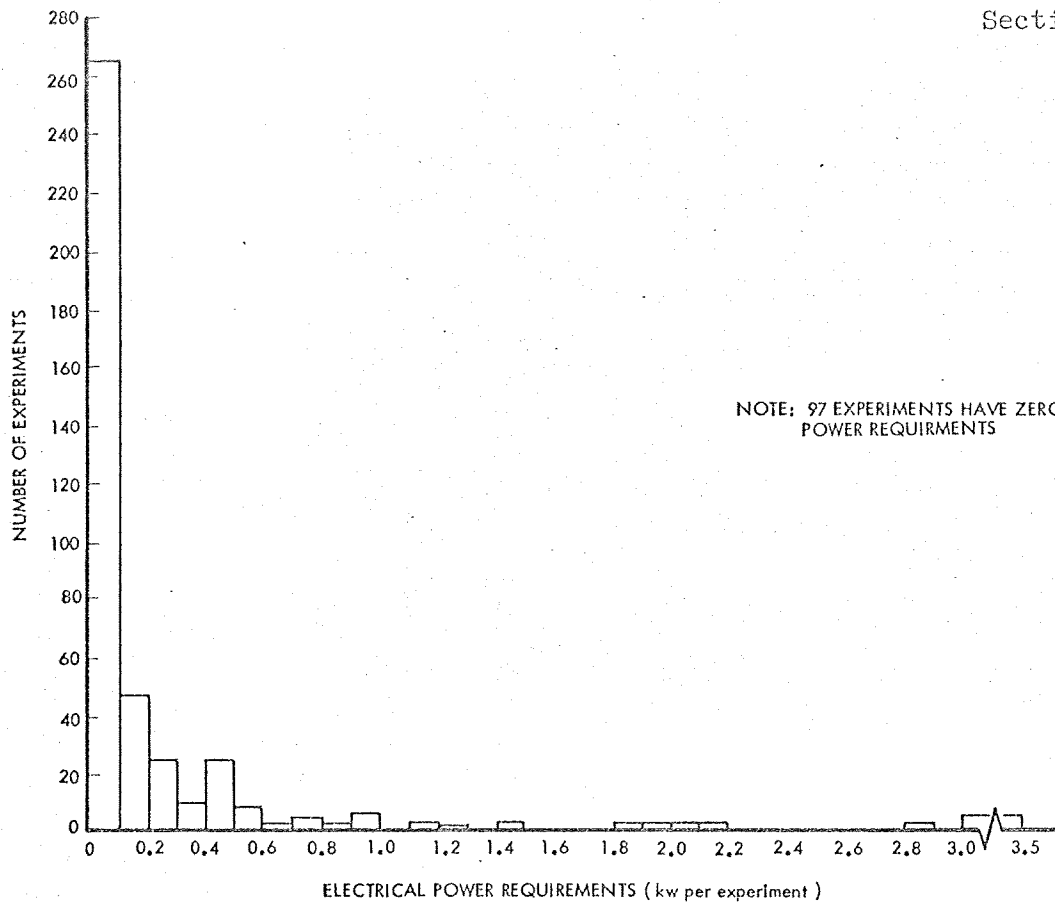


FIG. 5-18 DISTRIBUTION OF ELECTRICAL POWER REQUIREMENTS FOR EXPERIMENTAL EQUIPMENT

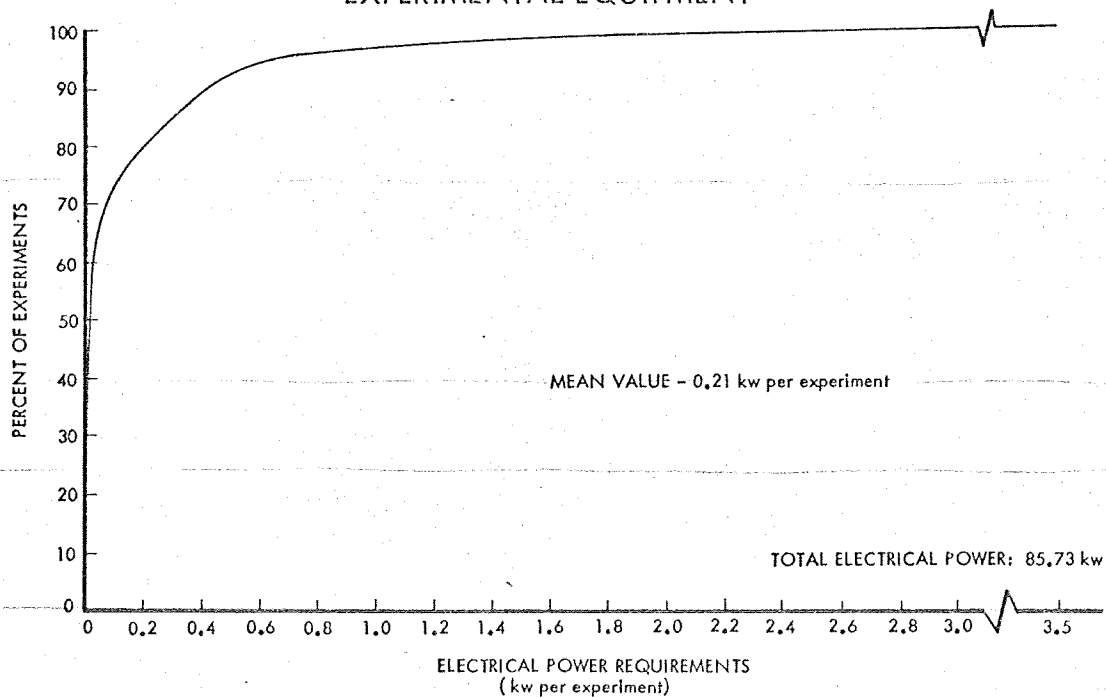


FIG. 5-19 CUMULATIVE DISTRIBUTION OF ELECTRICAL POWER REQUIREMENTS FOR EXPERIMENTAL EQUIPMENT

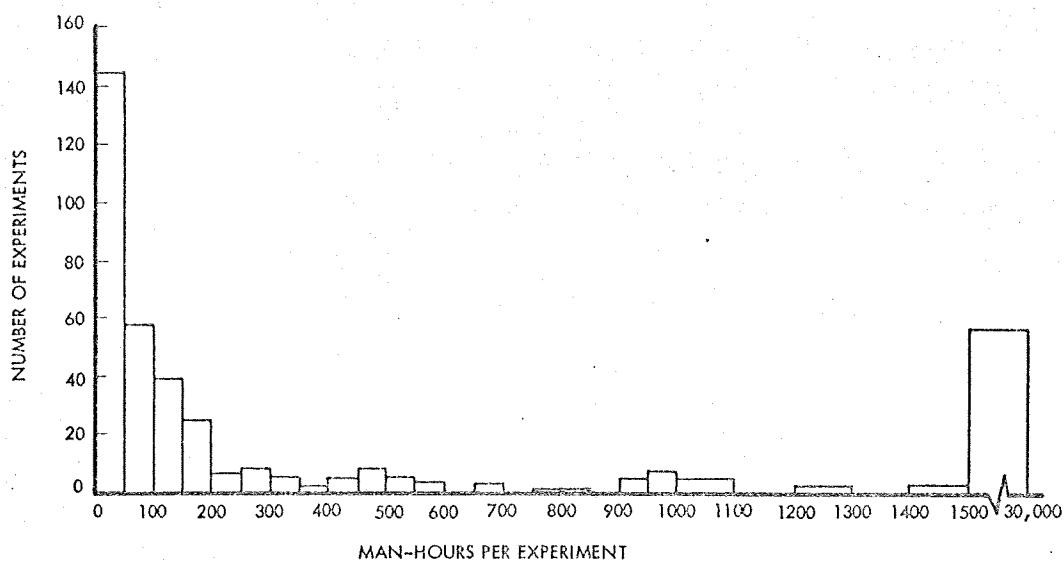


FIG. 5-20 DISTRIBUTION OF EXPERIMENT MAN-HOUR REQUIREMENTS

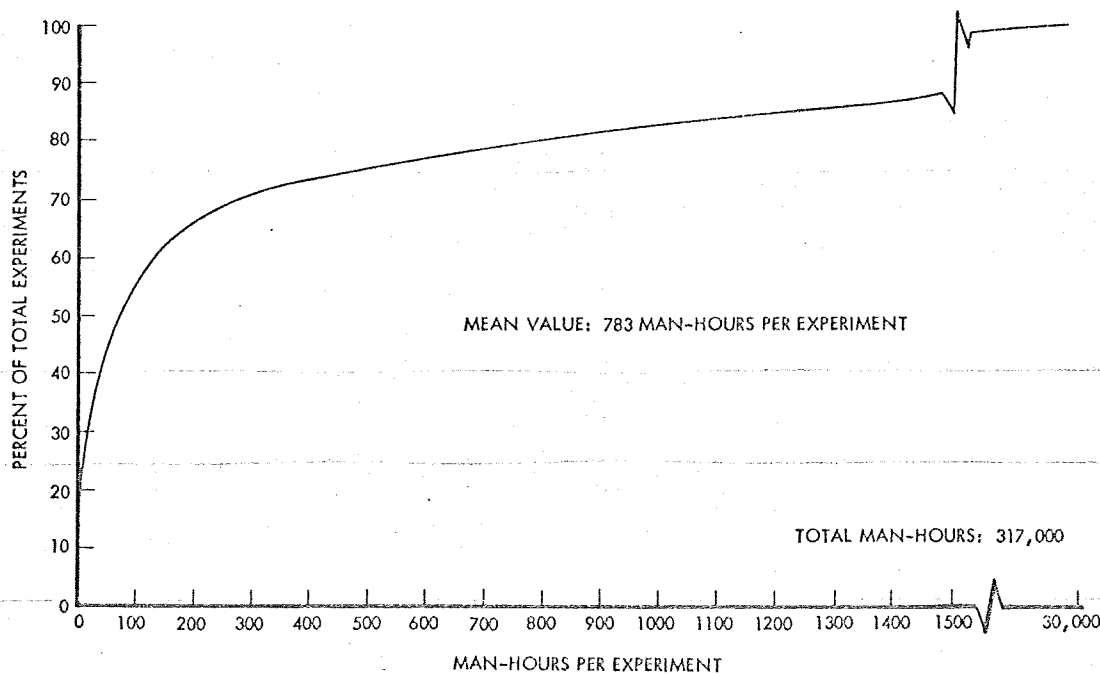


FIG. 5-21 CUMULATIVE DISTRIBUTION OF EXPERIMENT MAN-HOUR REQUIREMENTS

Finally, Figs. 5-20 and 5-21 show the distributions of man-hours per experiment. The mean is 783 man-hours per experiment with 80 percent of the experiments having this value or less.

Table 5-12 shows a further breakdown of mean values for the various categories of experiments and applications. In addition, the overall mean values are tabulated for weight, stored volume, power, and man-hours for all 405 experiments.

Table 5-12
EXPERIMENT CHARACTERISTICS SUMMARY

	WT/EXP. (lb)	VOL/EXP. (cu ft)	PWR/EXP. (kw)	MAN-HOURS/EXP.		
				Mission Duration	Others	All. Experiments
Life Science	31	9.6 (with centrifuge) 3.1 (w/o)	0.11	1340	140	226
Space Environment	74	4.9	0.13	4660	231	1278
Astronomy/Geoscience	594	12	0.38	3360	915	2380
Physics/Chemistry	160	6.9	0.18	905	338	528
Engineering Development & Qualification	180	13	0.26	1160	232	349
Earth Oriented Functional Applications	34	1.2	0.13	2320	48	2050
Space Mission Support	3520	85	0.55	7620	309	2580
National Defense Support	1600	50	3.5	-	5824	5824
All Categories (Mean)	270	13	0.21	2420	240	783

5.3 EXPERIMENT AND APPLICATIONS PROGRAMMING

The current mission model for the Modular Multipurpose Space Station family of vehicles consists of 405 experiments and applications. The task of sequentially scheduling these within the finite constraints of the space station is a major problem. To aid in this process, the DOES (Development of Events Sequences) computer program was developed. This stored computer program was written in the Cobol language for the IBM 7094. It takes as inputs specific experiment data requirements, and schedules the experiments within the constraints of available manhours per week, electrical power per week, priority and other limitations. The output lists the start date for each experiment and the end date, weekly manhour commitments for each skill type, power consumed per week, and the inability to schedule certain experiments within the established constraints. It also has the capability of scheduling experiments at some specified time delay after some particular independent experiment. If required, this time delay can take on the value of zero, so that certain experiments can be scheduled simultaneously as a block. A simplified logic diagram of the DOES program is shown in Fig. 5-22.

Examples of the print out of this program are shown in Tables 5-13 and 5-14. With the exception of the "start date" value, Table 5-13 is a print-out summary of the data input for each experiment. The columns in the table, from left to right, show test number, title, priority, start date (computed output), time span (weeks), power required (watt-hours/week), hours required of various crew skills (man-hours/week), cumulative manhours required, other test number on which the test is dependent, and the time delay between the two tests. The electrical and manpower constraints and requirements were chosen on a per-week basis to take advantage of the transient overload capabilities of the crew and the electrical power subsystem. If required after the preliminary grouping and scheduling, this time increment can be reduced to some more precise unit, such

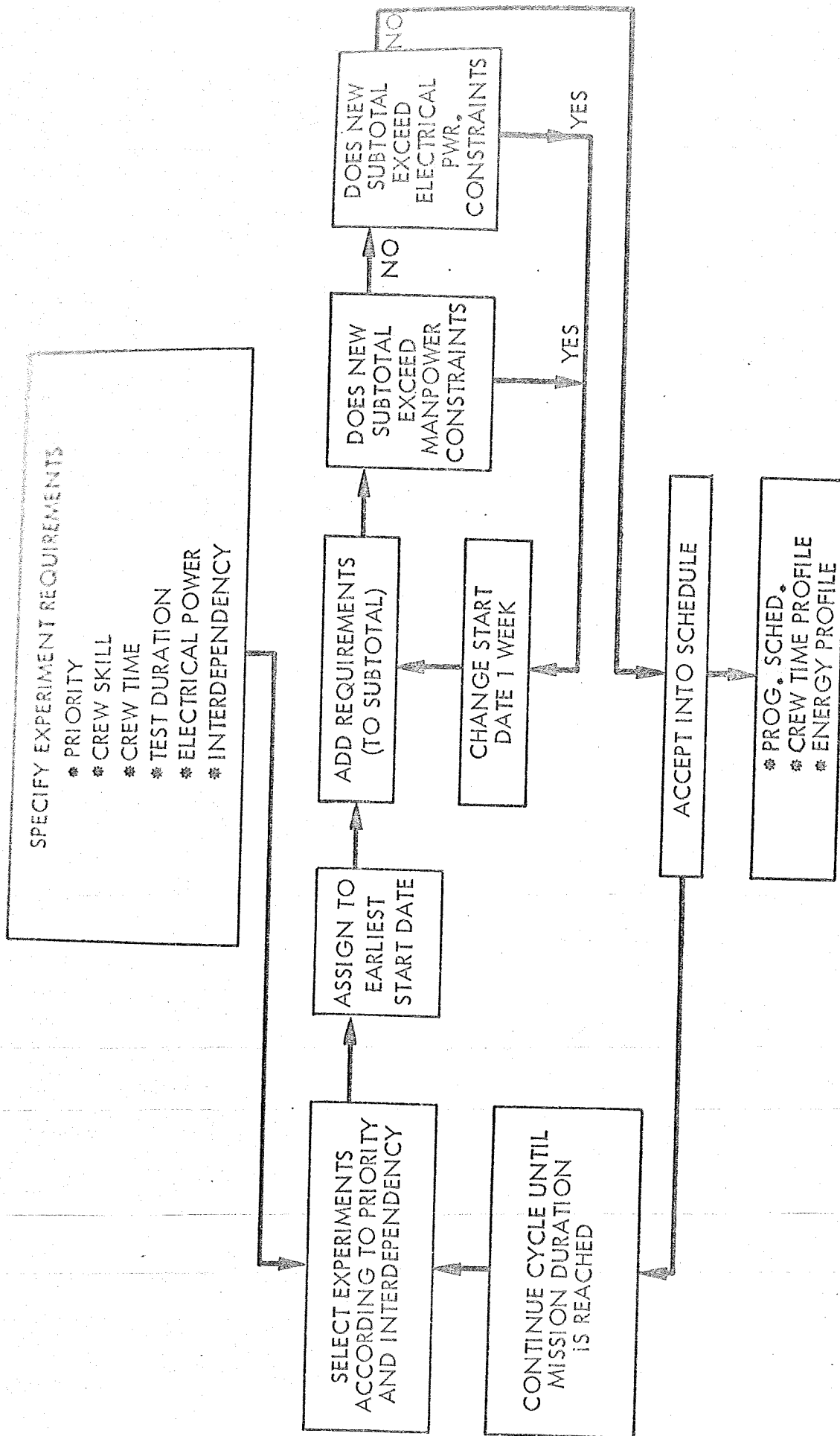


FIG. 5-22 DEVELOPMENT OF EVENTS SEQUENCES

Table 5-13

APPLICATIONS SCHEDULING—DATA PRINT-OUT

Test Num	Title	Prio- rity	Start Date Week	Time Span Weeks	Power WH/W	(Man-Hours Per Week)						Test NU-1	Time Delay Weeks
						Skill 1	Skill 2	Skill 3	Skill 4	Skill 5	Total Skill		
606	Reentry Communications Testing	2	027	1	20	0.0	4.0	0.0	0.0	0.0	4.0	605	12
621	Extravehicular Suit Training	1	001	16	150	0.0	0.0	3.0	0.0	15.0	18.0		
622	Rendezvous and Docking	1	001	3	300	0.0	9.0	0.0	0.0	6.0	15.0		
623	Rendezvous and Docking	1	016	3	300	0.0	9.0	0.0	0.0	6.0	15.0	622	12
624	Rendezvous and Docking	1	031	3	300	0.0	9.0	0.0	0.0	6.0	15.0	623	12
625	Rendezvous and Docking	1	046	3	300	0.0	9.0	0.0	0.0	6.0	15.0	624	12
627	Crew, Cargo Transfer Techniques	1	017	20	140000	0.0	112.0	0.0	0.0	0.0	112.0		
641	Zero-G Propel Tank Slosh, Vortex	2	016	1	280	0.0	56.0	0.0	0.0	0.0	56.0		
642	Restart Capability of Prop.	2	053	52	5	0.0	1.0	0.0	0.0	0.0	1.0		
643	Ion Propulsion Recombination	3	001	1	16800	0.0	0.0	0.0	0.0	0.0	0.0		
662	Stab. for Recon and Comm	2	019	8	700	0.0	14.0	0.0	0.0	0.0	14.0		
663	Earth, etc. Tracker Performance	3	037	8	700	0.0	14.0	0.0	0.0	0.0	14.0		
664	Drag Studies	2	014	1	20000	0.0	20.0	0.0	0.0	0.0	20.0		
666	Eval of Low Range Accelerometers	3	053	8	700	0.0	14.0	0.0	0.0	0.0	14.0		
681	Repair Therm Cont Surf in Space	2	053	52	400	0.0	6.0	0.0	0.0	0.0	6.0		
682	Study Space Maint Methods, Tools	2	034	9	20000	0.0	20.0	0.0	0.0	0.0	20.0	621	12
691	Advanced Photographic System Eval	3	053	6	7000	0.0	14.0	0.0	0.0	0.0	14.0	663	4
726	Mapping of Cloud Formations	3	053	52	2800	0.0	28.0	0.0	0.0	0.0	28.0	662	4
727	Map Changes in Snow, Ice Cover.	3	053	52	2800	0.0	28.0	0.0	0.0	0.0	28.0	662	4

Table 5-14
APPLICATIONS SCHEDULING - SUMMARY PRINT-OUT
Six Compartment Interim Space Station
Nine Man Crew, 260-Week Mission

Week	Total Power WH/W	(Man-Hours Per Week)					Total Skill
		Skill 1	Skill 2	Skill 3	Skill 4	Skill 5	
025	265166	8.2	330.2	46.0	0.0	24.8	409.2
026	265166	8.2	330.2	46.0	0.0	24.8	409.2
027	240086	8.2	316.0	46.0	0.0	24.8	395.0
028	239716	8.2	312.0	39.0	0.0	24.8	384.0
029	253116	8.2	344.0	39.0	0.0	24.8	416.0
030	249838	8.2	345.0	39.0	0.0	24.8	417.0
031	236778	8.2	227.6	39.0	0.0	30.8	305.6
032	235938	8.2	194.0	39.0	0.0	30.8	272.0
033	235238	8.2	180.0	39.0	0.0	30.8	258.0
034	226188	8.2	177.3	95.0	0.0	136.8	417.3
035	211066	8.2	149.3	95.0	0.0	136.8	389.3
036	211066	8.2	149.3	95.0	0.0	136.8	389.3
037	235346	8.2	176.3	95.0	0.0	136.8	416.3

as a day or an orbital period. The crew skills referred to are, by number:

1. Physician
2. Physical science experimenter
3. Biomedical science experimenter
4. Undesignated skill
5. Subject time.

Table 5-14 shows the computed characteristics of the integrated experiment program, where the columns, from left to right, show the week of operation, total power required, man-hours per week of the various skills, and the total man-hours for the particular week of experimentation. This tabular output can be plotted to show more readily the manpower and energy profiles. A sample plot, Fig. 5-23, shows that for the first seven weeks, manpower, the most prevalent constraint is limiting; however, changes in experiments at the seven-week point cause electrical power to become limiting. This particular schedule is interesting in that it suggests further schedule optimization or, failing to accomplish the desired result in this manner, an increase in the capacity of the electrical power subsystem. Increases in capacity of the power system imply economic trade-offs in power system costs versus manpower costs.

The DOES program was not applied to all 405 experiments for all vehicle configurations because of possible NASA contract duplications of effort; however, the program is operable, and with the use of a space station capability matrix such as shown in Table 5-15, and the potential experiment assignment list in the Appendix, experiment groupings and schedules could be formulated for the entire family of multipurpose space stations. It is suggested this task be carried out as part of a future study.

Although the DOES program is currently being refined and updated, it cannot accurately predict such time-consuming events as equipment or personnel failures, unexpected experiment results, experiment lead-in.

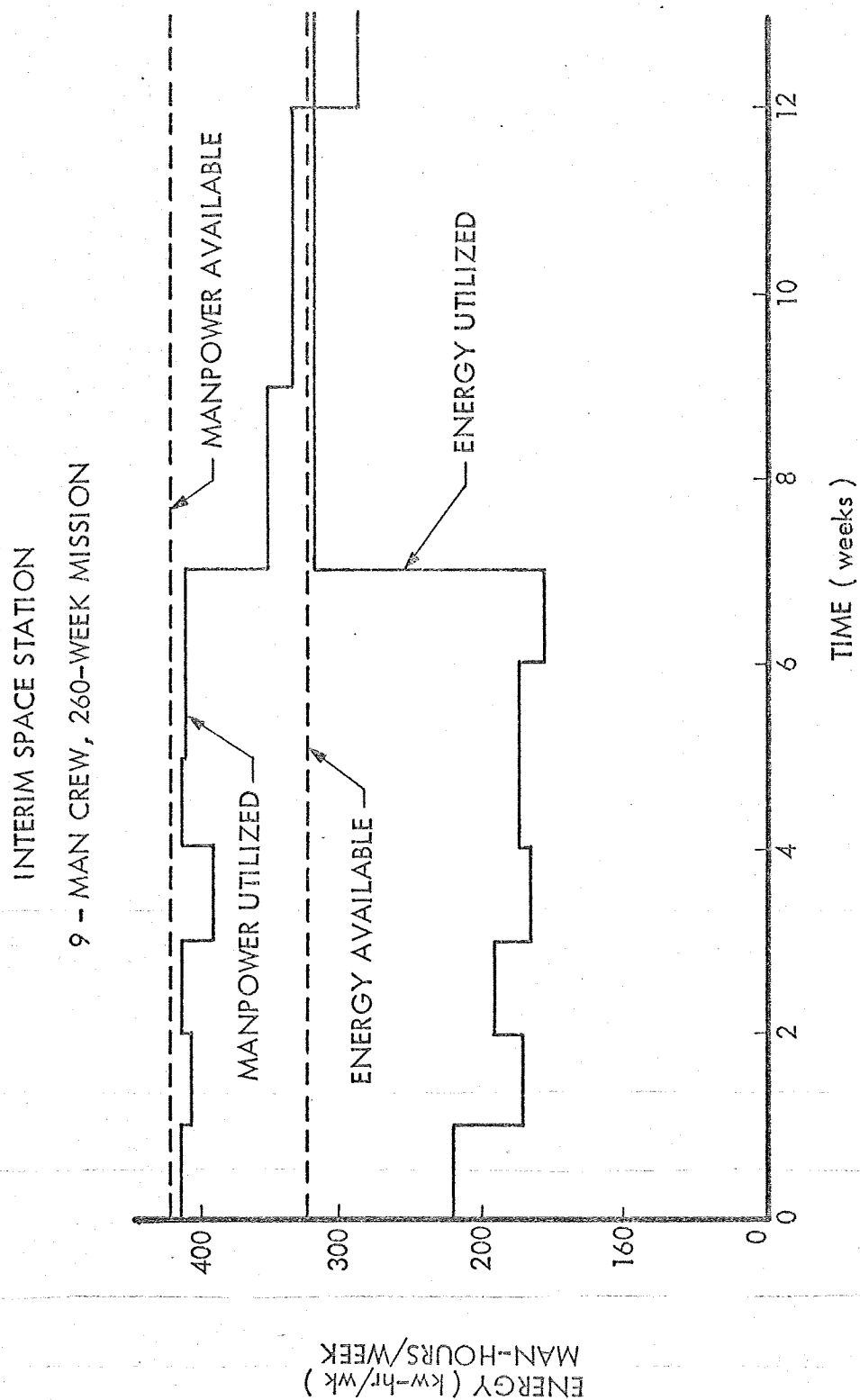


FIG. 5-23 APPLICATIONS SCHEDULING FIRST LOGISTIC CYCLE

Table 5-15
CAPABILITY OF SPACE STATION CONFIGURATIONS

STATION Available For Experiments	One- Compartment Dependent Laboratory	Two- Compartment Independent Laboratory	Two- Compartment Polar Laboratory	Two- Compartment Synchronous Laboratory	Interim Modular Multipurpose Space Station	Operational Modular Multipurpose Space Station
Equipment Weight (lb)	3300	8080	1560	10,470	41,000	67,620
Initial Consumable + Reserves (days)	45+5	90+90	90+30	90+45	90+90	90+90
Pressurized Volume (ft ³)	1250	2500	2500	2500	7500	69,530
Mission Duration (months)	1.5	3 to 12	3	3	12 to 60	60 to 120
Experimental Time 8/Man-Day Per Mission (Man-Hours)	1080	4320 to 17,280	2160/3 4320/6	2160/3 4320/6	25,920 to 129,600	345,600 to 1,036,800
	1350	5400 to 21,600	2700/3 5400/6	2700/3 5400/6	32,400 to 162,000	432,000 to 1,296,000
Electrical Power (KW)	0.4 to 1.9	1.2	0.9	1.1	2.1	10.6/2.9
Crew Size	3	6	3-6	3-6	6-9	24/36

and lead-out times, etc. Consequently, a need is foreseen for the continuous availability for a DOES, or equivalent, program aboard each of the space stations to minimize overloads or underloads to the vehicle capabilities. On the larger configurations, such a program could be built into the on-board computers, and on the smaller, ground-dependent systems, the results of the program could be made available through the communications link.

5.4 INTERIOR ARRANGEMENT PHILOSOPHY - INTERIM SPACE STATION

5.4.1 Crew Distribution and Scheduling

The interior layout of each compartment of the Interim Space Station is dependent upon:

- The availability of crewmen for experimental or station operation functions.
- The grouping of like experiments, i.e., the experiment allocation per compartment.

In analyzing the availability of crewmen, a model crew distribution was established. The crew of nine men establishes three shifts of three men each. This means that for any point in time, there are three men asleep and six men active at station operation, experimentation or off-duty activity. The six active crewmen are assumed to be dispersed about the six-compartment spacecraft as follows:

- A. Routine operations of the station from the control compartment are considered to require one man with another available as an assistant and intermittent replacement. It is practical for one man in each shift to be trained in this function. One of the two is also intermittently available to conduct experimentation located in the control compartment.
- B. It must be assumed that at least two crewmen will be in a bio-medical laboratory because of the routine data collection needs. Also, a number of the experiments and measurements require a subject and experimenter team.
- C. The two remaining men will participate in experimentation and observations in the physical sciences laboratory and the observatory compartment.

The nine-man crew offers a minor problem in scheduling. While it is quite evident that three shifts of three men each are in order, the meal shift arrangement is problematical. It was deemed inadvisable to eat in groups of three as this would leave only three men in sustaining experimentation. At the other extreme, if each were to eat alone, it would involve 27 meals in a 24-hour period and it is likely that experiment schedules would be jeopardized by minor galley mishaps. Therefore, a two man-per-meal arrangement was settled upon, even though the two

meals will not necessarily be similar, i. e. there may be one lunch and one dinner scheduled.

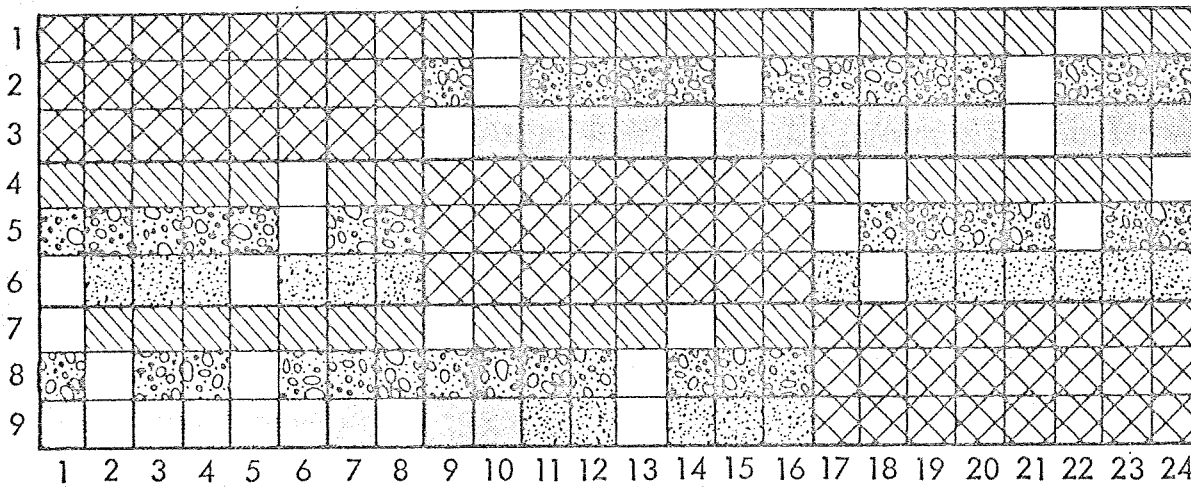
The accompanying diagram, Fig. 5-24 depicts a sample 24-hour schedule. The off-duty time has not been indicated, as that depth in analysis is not germane to the basic interior arrangement. The space suit stowage allocations are dependent upon the foregoing as are the working provisions in each compartment.

The men are grouped towards the living compartment end of the station and the greater preponderance of experimental equipment is toward the opposite end, with the principal docking and resupply at the greater distance from the crew accommodations. This situation makes it possible to provide maximum room where it is needed for the crew to relax and to carry out their routine activities, while the placement of major experimental equipment need not be influenced greatly by these restraints.

5.4.2 Work Area Configuration

An examination was made of floor patterns for equipment installation that would yield a maximum equipment density while retaining 30-inch aisles and work spaces. Figure 5-25 shows the conventional annular aisle. With the depth of the outer ring of equipment limited to 20 in. so that the volume lost in providing swing-out access to the wall is not excessive, this configuration uses 55 percent of the floor area for equipment installation. The "H" pattern, shown in Fig. 5-26 localizes major equipment on the axis normal to the side ports and increases the floor area used for equipment installation to 66 percent.

In the physical sciences laboratory, where there is a high equipment volume requirement, the "H" configuration is employed to advantage. It allows a vertical web across center of the laboratory to be utilized both as a launch load support member for the equipment, and as a partition capable of retaining a small pressure differential. This becomes quite useful in designing the toxic materials chamber.









-  CONTROL
-  MEDICAL
-  PHYSICS
-  OBSERVATORY
-  EAT
-  SLEEP

FIG. 5-24 NINE-MAN CREW SCHEDULE

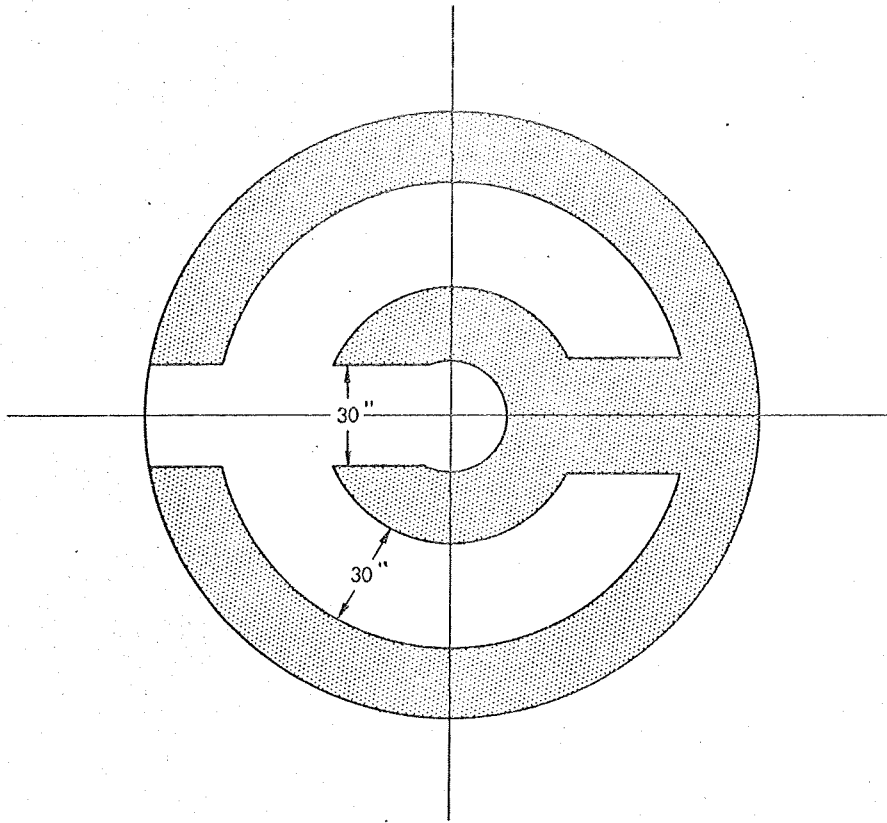


FIG. 5-25 WORK AREA CONFIGURATION WITH AN ANNULAR AISLE

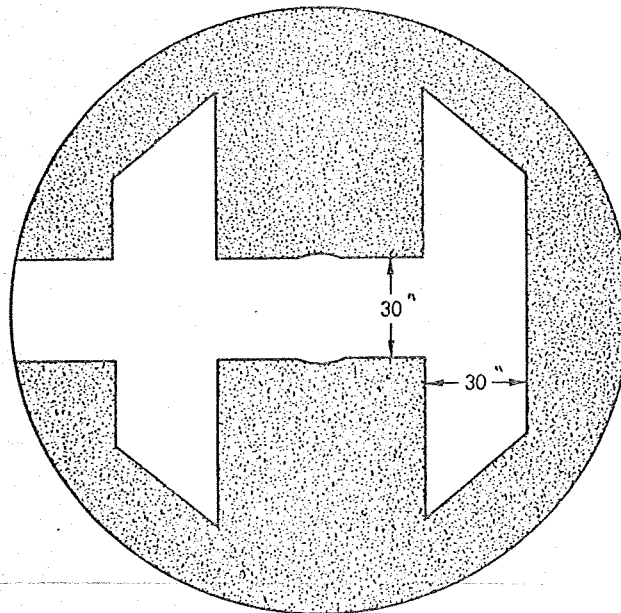


FIG. 5-26 WORK AREA CONFIGURATION WITH AN "H" AISLE

5.4.3 Experiment Allocation

Table 5-16 presents a summary of the number of experiments and their weight and volume utilization per compartment. The volume utilization is based upon a compartment volume of 1250 cu ft including the floor-ceiling interconnect tube volume of 43 cu ft.

The volume data of Table 5-16 are portrayed graphically in a bar chart, Fig. 5-27. Occupancy provisions*, occupancy for both six- and nine-man crews, and space suit stowage are also depicted in the bar chart.

Lists of the experiments that have been included in the design of each of the six compartments are given in Tables 5-17 thru 5-22. The experiment titles and numbers have been selected from "National Multipurpose Space Station Utilization Outline", dated October 1, 1964, published by the NASA-MSC Space Station Study Office.

5.4.4 Interior Arrangements

The four laboratory compartments of the Interim Space Station are shown in detail in Figs. 5-28 thru 5-31, showing the placement of the experimental equipment previously described.

5.4.4.1 Physical Sciences Laboratory

The interior arrangement of the Physical Sciences Laboratory is shown in Fig. 5-28. This laboratory is primarily for the testing of materials and components.

Section A-A shows a test material preparation area at the right. To the left of the interconnect tube is equipment used for the physical testing of fluids.

Section B-B shows at the right a large sample analysis chamber that can be sealed during tests. Various pieces of recording and test equipment are located to the left of the centerline interconnect tube.

The plan view shows usage of the two external hatches. One is used for exposing materials to the outside environment; the other hatch is used for the meteoroid gun and reentry model launching. It is used also for

*Occupancy provisions: the number of men who can work or function in a compartment.

Table 5-16
SUMMARY OF EXPERIMENT ALLOCATION TO INDIVIDUAL COMPARTMENTS

COMPARTMENT NUMBER	NUMBER OF EXPERIMENTS	EXPERIMENT EQUIPMENT WEIGHT (lb)	EXPERIMENT EQUIPMENT VOLUME (cu ft)	EXPERIMENT AND OPERATIONAL		PERCENT COMPARTMENT VOLUME UTILIZED
				EXPERIMENT EQUIPMENT VOLUME (cu ft)	OPERATIONAL EQUIPMENT VOLUME (cu ft)	
1	14	2730	205.6	659.0	54.0	
2	77	6370	504.8	519.5	43.0	
3	83	7609	512.2	653.0	53.5	
4	123	1523	149.7	504.0	41.0	
5	31	2880	122.7	474.0	39.0	
6	5	100	6.5	383.5	31.0	
TOTAL	333	21,212	1501.5	3193.0	Average 43.5	

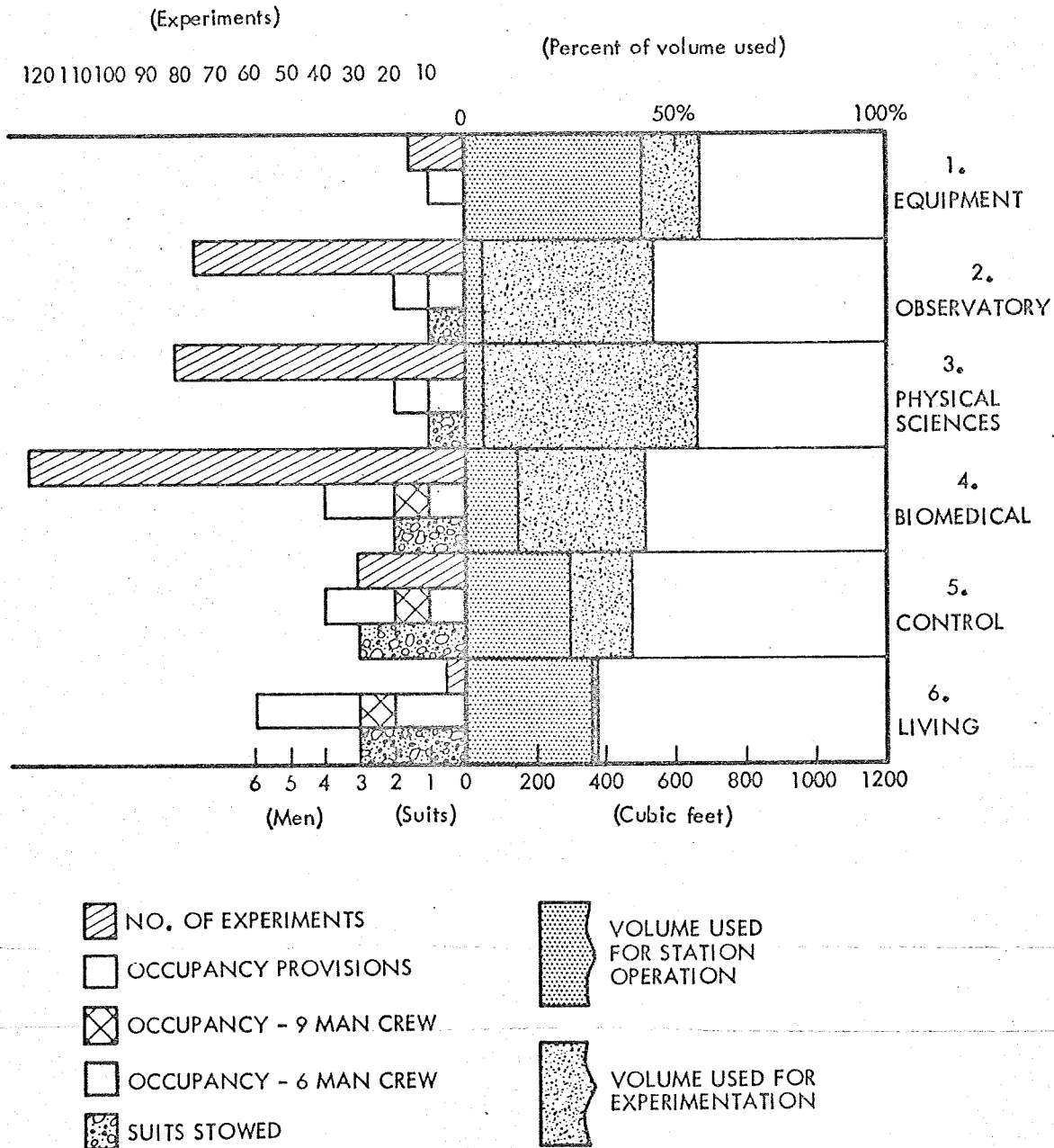


FIG. 5-27 UTILIZATION OF VOLUME IN INDIVIDUAL COMPARTMENTS

Table 5-17

EXPERIMENTS SELECTED FOR COMPARTMENT 1, SUBSYSTEMS COMPARTMENT

1.1.3.6	Long-Term Animal Exposure
1.1.3.12	Experimental Analysis of Animal Adjustment in Various Degrees of Gravitational Force
1.1.3.17	Discrimination & Communication of Animals Under zero-g Conditions
1.1.3.19	Changes in Sex Distribution of Offspring Conceived, Developed, and Born in the Weightless State
2.1.1.1	Performance & Reliability Data of Secondary Environmental Control System
2.1.2.1	Test of Garbage & Waste Disposal Methods
2.1.1.4	Transient Effects of Varying Heat Load on ECS
2.1.2.15	Urine Purification System Functional Tests
2.4.2.1	Rendezvous and Docking
2.4.2.2	Crew Transfer & Cargo Handling
2.11.1.5	Crew & Cargo Transfer Techniques
2.1.2.13	Solid Waste Reclamation under Zero-g
2.1.2.2	Development of Regenerative Oxygen Supply Systems Under Zero-g
2.1.2.14	Test of Regenerative Water Supply System Under Zero-g

Table 5-18

EXPERIMENTS SELECTED FOR COMPARTMENT 2, OBSERVATORY

1.2.4.2	Horizon Spectrometry
1.2.1.1	Extraterrestrial Electromagnetic Radiation Survey
1.2.3.3	Measurement of Earth Origin Electromagnetic Radiation Spectrum & Distribution
1.2.4.6	Measurements of Local Spacecraft External Atmosphere
1.4.1.1	Multispectral Sensing of the Terrestrial Surface
1.4.1.2	Photography of the Terrestrial Surface
1.4.1.3	Monitoring of Earth's Vegetation by IR
1.4.1.12	Cartography
1.4.1.4	Infrared (7-30 microns) Response of Geologic Materials
1.4.1.10	Geographic Studies
1.4.1.13	Geodetic Survey
1.4.1.8	Spectral Photographic Response
1.4.1.14	Determination of Composition and Distribution of Rock Types from Infrared Emission Mission Imagery
1.4.1.9	Multispectral Photography, Film Filter Oriented
1.4.2.2	Multispectral Sensing of Lunar Surfaces
1.4.2.3	Photography of Lunar Surfaces
1.4.1.5	Infrared-UV Spectral Emittance
2.9.1.11	Evaluation of Stabilization Systems for Laser Communications
2.9.1.3	Evaluation of Lock-on Systems for Terrain Reconnaissance and Communication
2.9.2.4	Techniques for Trailing Test Units from Space Station
2.9.1.4	Evaluation of Low Range Accelerometers
2.9.2.3	Test & Evaluation of Control System Torqueing Devices
2.9.1.10	Development Tests of Gravity Gradient Components & Techniques
2.9.1.2	Horizon-Scanning Infrared Sensor

Table 5-18 (cont)

EXPERIMENTS SELECTED FOR COMPARTMENT 2, OBSERVATORY

2.9.1.7	Gyro Drift Tests
2.9.1.9	Radiation Sensors to Determine Earth's Vertical
2.9.1.6	Evaluation of Inertial Components
2.9.1.8	Optical Scanners
1.3.1.15	Measurement of Lunar Temperatures Using a Spectrometer
1.3.2.1	Observations of Earth-Surface Detail in 8 to 16 micron Band Pass
1.3.2.2	Electro-Optical Experiment
1.3.2.5	Radio Astronomy Star Resolution
1.3.3.2	Spectral Analysis of Star Sources Useful for Space Navigation
1.3.3.4	Evaluation of Pertinent Factors in High Resolution Space Photo Reconnaissance
1.3.4.9	Observation of Ionized Cloud in Space
1.3.1.8	Stellar Background Measurements
3.1.1.2	Mapping of Changes in Snow & Ice Coverage
3.1.1.3	Monitoring Jet Stream
3.1.1.6	Fog/Smog Survey and Prediction
3.1.1.5	Hurricane Watch & Warning
3.1.2.2	Clear Air Turbulence Study & Prediction
3.3.1.3	Ship Routing and Control
3.3.1.2	Search and Rescue
3.3.1.1	Navigation Aid for Ships at Sea
3.4.1.14	Determine Composition of Soils from Spectral Infrared Emission
3.4.2.7	Iceberg Position Status
3.4.2.6	Tidal Wave Warning
3.4.1.7	Forest Fire Warning
3.4.2.3	Sea Temperature Gradients
3.4.1.2	Water Resources Survey
3.4.1.11	Mineral Survey

Table 5-18 (cont)

EXPERIMENTS SELECTED FOR COMPARTMENT 2, OBSERVATORY

3.4.1.10	Optimum Use of Habitable Land
3.4.1.3	Geodetic & Topographic Mapping
3.4.1.1	Survey & Dynamic Mapping of the Earth's Surface for Agricultural Production Estimates
3.4.2.9	Fish Migration
3.4.1.5	Forestry Survey
3.4.1.8	Crop Prediction
3.4.2.1	Oceanography Studies
3.4.2.2	Remote Sensing of Broad Scale Hydrologic Phenomena
3.4.2.5	Ocean Currents Analysis
3.4.1.13	Earthquake Observations
3.4.1.12	Observation of Volcanic Eruption Effects
3.4.1.6	Agricultural Survey
3.4.1.9	Monitor Earth's Vegetation
3.4.2.10	Whale Migration
3.4.1.15	Determination of Composition and Distribution of Soil Types from Infrared Emission Imagery
3.4.1.16	Atmospheric Modification of the Infrared Spectral Reflectance and Emittance from Vegetation
3.4.2.12	Thermal Structure and Patterns of the Ocean Surface from Spectral Infrared Emittance
3.4.2.13	Determination of the Thermal Pattern and Structure of the Ocean Surface by Imaging the Emitted Infrared Radiation
3.5.2.3	Radioactivity Level Survey
3.5.2.4	Community Planning
3.5.2.5	Industrial Planning

Table 5-19

EXPERIMENTS SELECTED FOR COMPARTMENT 3, PHYSICAL SCIENCES LABORATORY

1.2.2.1	Micrometeroid Environment Mapping
1.2.1.2	Bubble Chamber Experiment
1.2.2.2	Micrometeroid Composition & Velocity
1.2.2.3	Projection of Artificial Meteroids into the Earth's Atmosphere
1.2.4.4	Measurements of Jet Flow in Vacuum
1.4.3.4	Study of Planetary & Satellite Surface Properties
1.5.3.4	Particle-Particle Studies
1.5.1.2	Heat Transfer in Liquids & Gases under Zero-g
1.5.1.3	Absorption of Gases by Liquids at Zero-g
1.5.1.4	Density Profiles of Liquids in the Critical Region
1.5.1.5	Static & Motion Tests of Interface Phenomena
1.5.1.6	Study of Convective Heat Transfer at Zero-g
1.5.1.13	Thermal Conductivity of High Pressure Gases under Zero-g
1.5.2.6	Plasma-Electromagnetic Interactions
1.5.3.2	High Energy Particle Physics
1.5.3.3	Study of High Energy Particle Physics Using Spark Chamber
1.5.3.6	Particle-Surface Interactions
1.5.4.2	Measurement of Nongravitational Forces
2.1.2.3	Photosynthetic Gas Exchanger Tests
2.1.2.8	Fire Extinguishment under Zero or Partial Gravity Conditions
2.1.2.16	Magnetic Radiation Shielding Evaluation
2.1.2.7	Algae Closed Cycle Life Support Systems
2.2.1.1	The Effect on Materials of Long-Term Exposure to the Space Environment
2.2.3.2	Tests of Self-Sealing Structures
2.2.1.2	Fatigue Tests of Materials after Exposure to Space Environment

Table 5-19 (cont)

EXPERIMENTS SELECTED FOR COMPARTMENT 3, PHYSICAL SCIENCES LABORATORY

2.2.1.4	Behavior of Thermal Control Surfaces in Space
2.2.1.5	Structural Damage Determination Caused by Meteoroid Penetration
2.2.5.1	Leak Detection & Sealing Techniques
2.2.1.6	Liquid Lubricant Life under Zero-g and One-Sixth Gravity Conditions
2.2.1.7	Liquid Lubricant Recovery under Zero-g Conditions
2.2.5.2	Analysis of Outgassing of an Orbiting Space Vehicle by use of a Mass Spectrometer
2.2.1.8	Determination of Thermal Conductivities of Materials at Zero-g
2.2.1.9	Cold Welding of Metals in a Space Environment
2.2.3.1	Deployment & Structural Stability Tests
2.2.4.2	Deployment & Structural Stability Tests
2.2.4.3	Radiation Shadow Shield Tests
2.2.2.6	Radiation Shielding Materials Testing
2.2.1.19	Fluid & Gas Permeability of Various Elastomers
2.3.1.2	Deployment of Foam-Rigidized Solar Collectors
2.3.1.4	Deployment & Erection of Large Area Solar Collectors
2.3.1.5	Deployment & Erection of Large Area Space Radiators
2.3.1.7	Evaluation of Solar Mercury Rankine System
2.3.1.9	Photovoltaic & Photoemissive Material Deterioration Evaluation
2.3.1.10	High Sensitivity Photo Detectors
2.4.1.1	Liquid Lubricant Systems under Zero-g Conditions
2.4.1.2	Study of Whirl Instabilities in a Hydrodynamic Journal Bearing Operating under Zero-Gravity Conditions
2.4.2.4	Deployment Devices
2.4.2.5	Redesign of Mechanical Fasteners

Table 5-19 (cont)

EXPERIMENTS SELECTED FOR COMPARTMENT 3, PHYSICAL SCIENCES LABORATORY

2.8.1.1	Zero-G Propellant Tank Slosh & Vortexing
2.8.1.2	Re-start Capability after Long Exposure to Space
2.8.2.1	Ion Propulsion Recombination
2.8.1.3	Leakage of Propellants
2.8.1.5	Test of Propellant Activated Device Components in Space Environment
2.8.2.8	Test of an Electric Propulsion Unit
2.9.2.1	Evaluation of Reaction Control Components
2.10.2.2	Study of Space Maintenance Methods & Tools
2.10.1.1	Joining Materials & Components in Space
2.10.1.2	Application of Thermal Control Coatings in Space
2.10.2.3	Repair of Heat Shield in Space
2.10.2.8	Determination of Fabrication & Sealing Techniques & Heat Transfer Patterns for Structural Parts
2.10.2.7	Meteoroid Hit Repair
4.3.3.3	Reentry Tests
4.1.1.2	Analysis of Maintenance Problems in a Zero-g Environment
2.2.1.25	Heat Transfer & Radiation Properties of Solid, Matrix & Filled Thermal Insulators
2.2.1.12	Effect of Space Environment on Ablative Materials
2.2.1.14	Fatigue Crack Propagation in a Vacuum
2.2.1.11	Measurement of Solar Absorptivity & Thermal Emissivity of Thermal Control Coating by Spectrophotometry
2.2.1.37	Radiation Heat Transfer
2.2.1.35	Breathing Mode and Fluid Behavior in Zero-G Space Environment
2.2.1.20	Polymerization of Elastomeric Monomers
2.2.1.21	Decompressional Fatigue of Rubber Mechanical Items
2.2.2.1	Thermal Strains in Spaceframe Structure & Insulation

Table 5-19 (cont)

EXPERIMENTS SELECTED FOR COMPARTMENT 3, PHYSICAL SCIENCES LABORATORY

2.2.2.3	Structural Damping Measurements
2.2.5.3	Internal Laboratory Spacecraft Environment Noise & Vibration Levels
2.2.1.10	Activation Measurements
2.2.1.30	The Effects of High Energy Particulate Radiation on Selected Materials - Particularly Organic Compounds
2.2.1.13	Effects of Space Environment on the Wear Properties of Metals
2.2.2.5	Pressure Loss Through Structural Organic Material
2.2.2.4	Determine Corrosive Effects on Space Station Resulting from Propellant Boil-Off
2.2.1.15	Environment Correlation
2.2.1.36	Evaluation of Elastomers
2.2.1.33	Meteoroid Effects on Materials and Surfaces
2.2.1.34	Meteoroid Penetration of Materials



Table 5-20

EXPERIMENTS SELECTED FOR COMPARTMENT 4, BIOMEDICAL LABORATORY

1.1.1.1	Pulmonary Pathology & Heart Size
1.1.1.2	Evaluation of Superficial Sensation
1.1.1.3	Blood Volume
1.1.1.5	Cardiac Electrical Activity & State
1.1.1.6	Venous Pressure & Circulation Time
1.1.1.7	Exercise Test
1.1.1.8	Cardiac Output & Heart Movement
1.1.1.9	Blood & Urine Potassium & Sodium
1.1.1.10	Muscle Function
1.1.1.11	Blood Catecholamine
1.1.1.12	End Expiratory pCO_2 & pO_2
1.1.1.13	Voiding Evaluation
1.1.1.14	Kidney & Bladder Stone Formation
1.1.1.15	Red Blood Cell Mass
1.1.1.16	Eosinophil Count
1.1.1.17	Capillary Fragility
1.1.1.18	Visual Fields Evaluation
1.1.1.19	Incisional Healing & Bleeding Time
1.1.1.20	Respiratory Rate
1.1.1.21	Mucosal Integrity Evaluation
1.1.1.22	Cardiopulmonary Symptoms
1.1.1.23	Skin Thickness
1.1.1.24	Venous Distension
1.1.1.25	Nausea-Regurgitation Evaluation
1.1.1.26	Blood Bilirubin
1.1.1.27	Body Temperature
1.1.1.28	Tubular Reabsorption Test
1.1.1.29	Energy Requirements
1.1.1.30	Gastrointestinal Tract Motility

Table 5-20 (cont)

EXPERIMENTS SELECTED FOR COMPARTMENT 4, BIOMEDICAL LABORATORY

1.1.1.31	Color Vision Evaluation
1.1.1.32	Urine 17 kg Steroid
1.1.1.33	Heart Sounds
1.1.1.34	Muscle Size
1.1.1.35	Urine & Fecal Nitrogen
1.1.1.36	Reflex Response & Clonus Evaluation
1.1.1.37	Bowel Function Evaluation & Stool Characteristics
1.1.1.38	Vestibular Reaction
1.1.1.39	Cortical Activity
1.1.1.40	Eating Habits Evaluation
1.1.1.41	Pulse Rate
1.1.1.42	Autonomic Hyperactivity
1.1.1.43	State of Arousal
1.1.1.44	Blood & Urine Sugar
1.1.1.45	Visual Activity, Depth Perception and Accomodation
1.1.1.46	Cerebral Blood Flow
1.1.1.47	Urine Bilirubin
1.1.1.48	GI Absorption Test
1.1.1.49	Urine & Fecal Occult Hemorrhage
1.1.1.50	Capillary Morphology
1.1.1.51	Protein Assimilation
1.1.1.52	Blood & Urine Chloride
1.1.1.53	Blood 17 kg Steroid
1.1.1.54	Prothrombin Time
1.1.1.55	Blood, Salivary & Urine Delayed Analysis
1.1.1.56	Respiratory Volume
1.1.1.57	Bromsulphalein (BSP)
1.1.1.58	Incidence of Aerotitis Media
1.1.1.59	Expiratory-Inspiratory Force

Table 5-20 (cont)

EXPERIMENTS SELECTED FOR COMPARTMENT 4, BIOMEDICAL LABORATORY

1.1.1.60	Blood Plasma Protein Fractionation
1.1.1.61	Glomerular Filtration Test
1.1.1.62	Blood Alkaline Phosphate
1.1.1.63	Tubular Excretion Test
1.1.1.64	Complete Blood Cell Count
1.1.1.65	Oxygen Uptake and Carbon Dioxide Production
1.1.1.66	Blood Pressure
1.1.1.67	Fluid Intake and Output Evaluation
1.1.1.68	Blood Osmolarity
1.1.1.69	RBC Uptake I_{125}
1.1.1.70	Oxygen Uptake by Red Blood Cells
1.1.1.71	Blood-Urea Nitrogen
1.1.1.72	Visual Illusion Evaluation
1.1.1.73	Hearing
1.1.1.74	Joint Motion Range
1.1.1.75	Urinary Albumin
1.1.1.76	Bacteria Smears and Cultures
1.1.1.77	Red Blood Cell Survival
1.1.1.78	Blood ATP
1.1.1.79	Retinal Examination
1.1.1.80	Urine Catecholamine
1.1.1.81	Pulse Wave Velocity
1.1.1.82	Liver Size
1.1.1.83	Gas Formation and Passage
1.1.1.84	Venous pCO_2 , pO_2 , pH
1.1.1.85	Muscle Activity and State
1.1.1.86	General Physical Examination
1.1.1.87	Bone Density
1.1.1.88	Blood and Urine Creatinine
1.1.1.89	Hemoglobin and Hematocrit

Table 5-20 (cont)

EXPERIMENTS SELECTED FOR COMPARTMENT 4, BIOMEDICAL LABORATORY

1.1.1.91	Urinalysis
1.1.1.92	Total Body Water
1.1.1.93	Calcium Balance Study
1.1.1.94	Comparison of the Usefulness of the Ballistocardiograph & the Vibrocardiograph
1.1.1.95	Evoked Electromyography during Weightlessness
1.1.1.96	Toxiological Studies of Respiratory Gases in Manned Spacecraft
1.1.2.1	Distant Static Depth Perception
1.1.2.5	Detection of Light Touch
1.1.2.7	Brightness Detection/Discrimination
1.1.2.8	Association
1.1.2.9	Sound Localization
1.1.2.11	Detection of Heat/Cold
1.1.2.12	Pain Detection
1.1.2.13	Olfaction
1.1.2.14	Texture Discrimination
1.1.2.15	Detection/Discrimination of Linear & Angular Acceleration
1.1.2.16	Inductive Reasoning
1.1.2.17	Detection/Discrimination of Force Against Limb
1.1.2.18	Arm/Hand/Finger Reaction Time & Speed Control
1.1.2.20	Leg Control of Force
1.1.2.21	Near Depth Perception
1.1.2.23	Tone Audition
1.1.2.24	Peripheral Visual/Detection/Discrimination
1.1.2.26	Vibration Detection/Discrimination
1.1.2.28	Arm/Hand/Finger Manipulation
1.1.2.33	Speech and Speech Perception
1.1.3.1	Embryology at Zero-g

Table 5-20 (cont)

EXPERIMENTS SELECTED FOR COMPARTMENT 4, BIOMEDICAL LABORATORY

1.1.3.3	Micro-Organism Exposure to Space Environment
1.1.3.5	Plant Physiology
1.1.3.7	The Independent & Synergistic Effects of Radiation and Zero-Gravity on Differentiation in the Flour Beetle
1.1.3.10	Effect of Weightlessness on Dividing Human Cells in Culture
1.1.3.15	The Function & Dysfunction of the Gravity-Sensitive Organ in Zero-G
1.1.3.16	Effect of the Space Environment on the Feeding, Survival, and Reproduction of Daphnia Pulex
1.1.3.18	A Study of Photosynthetic Action Spectra During Exposure of Algae Cultures to True Space Illumination
1.1.3.24	Collecting and Sampling of Microorganisms in Near-Earth Orbits
4.5.2.1	Conditioning Before Re-Entry for Returning Spacecraft Crews
4.5.1.1	Quarantine for Returning Spacecraft Crews
4.5.2.2	Medical Aid for Returning Spacecraft Crews

Table 5-21

EXPERIMENTS SELECTED FOR COMPARTMENT 5, CONTROL COMPARTMENT

1.1.2.2	Dynamic Depth Perception
1.1.2.4	Decision Making
1.1.2.3	Cue Abstraction
1.1.2.6	Problem Solving
1.1.2.10	Tone Pattern Discrimination
1.1.2.19	Visual-Motor Tracking
1.1.2.22	Visual Resolution of Detail
1.1.2.23	Tone Audition
1.1.2.25	Color Detection/Discrimination
1.1.2.27	Time Perception
1.1.2.30	Computation
1.1.2.29	Complex Pattern Discrimination
1.1.2.31	Learned Procedure
1.1.2.34	Perceptual Set
4.2.2.2	Evaluation of Ground Training Techniques for Space Crews
4.2.2.1	Feasibility of using Space Station for Training, Training Simulators & Devices
1.5.2.2	Study of Atmospheric Effects on Electromagnetic Wave Propagation
1.5.2.3	Determination of the Frequency Distribution of Cosmic Noise
1.5.2.11	Millimeter Wavelength Space Propagation Measurements
2.1.3.1	Tests of Personnel Restraint Equipment
2.3.1.6	Evaluation of Petal Type (Sunflower) Solar Dynamic System
2.3.1.11	Solar Thermionic Static Power Generating System
2.5.1.1	Advanced Guidance System Evaluation
2.5.2.1	Development of Space Navigational Aids & Techniques
2.5.2.5	Navigation Fixes with Simple Instruments

Table 5-21 (cont)

EXPERIMENTS SELECTED FOR COMPARTMENT 5, CONTROL COMPARTMENT

2.5.2.3	Comparative Evaluation of Navigation Techniques
2.5.2.4	Demonstration of Reliable Autonomous Navigation Capability
2.6.1.2	Free Space Antenna Pattern Determination
2.6.1.4	Re-entry Communications Testing
2.6.1.9	Magnetic Effects on Communication Systems
2.8.3.1	Nuclear Propulsion Techniques

Table 5-22

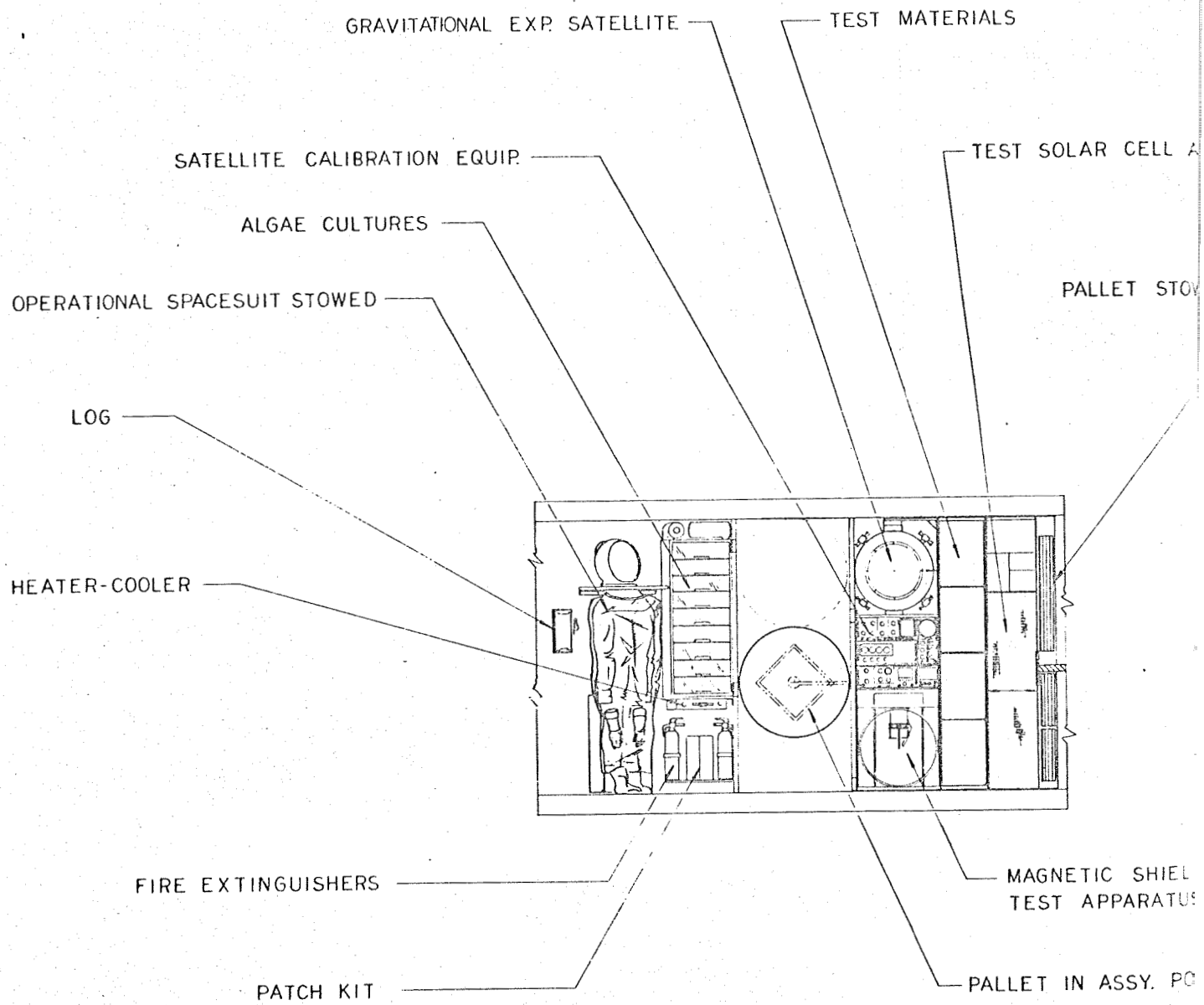
EXPERIMENTS SELECTED FOR COMPARTMENT 6, CREW QUARTERS

2.1.3.1	Tests of Personnel Restraint Equipment
2.1.3.3	Weightless Condition Feeding Devices
2.1.2.9	Fecal Collection Unit, Functional Tests
2.1.3.2	Feasibility Test of Special Bed for Use Under Weightless Condition
2.1.2.10	Tests to Evaluate Food Storage & Preparation under Zero-g

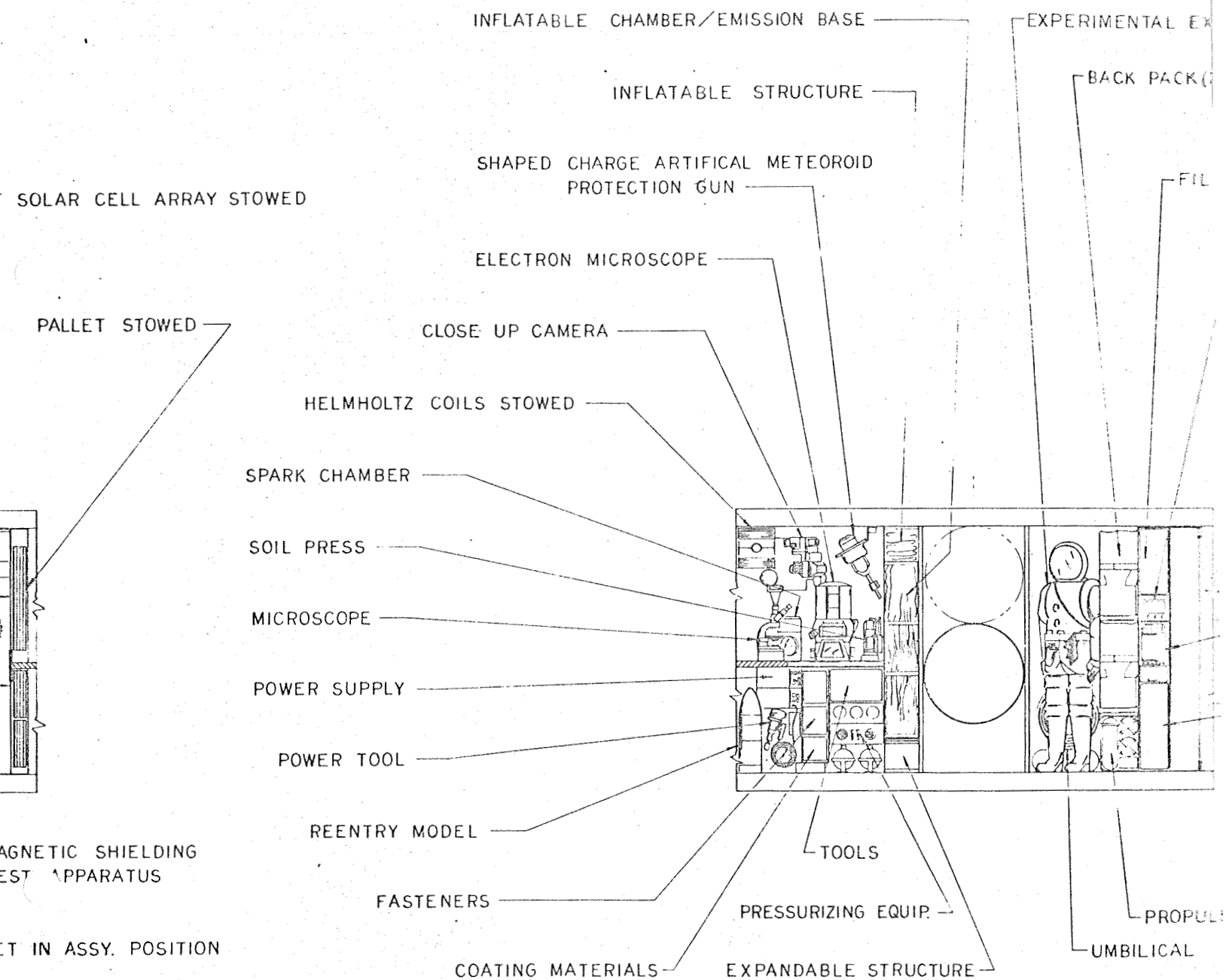


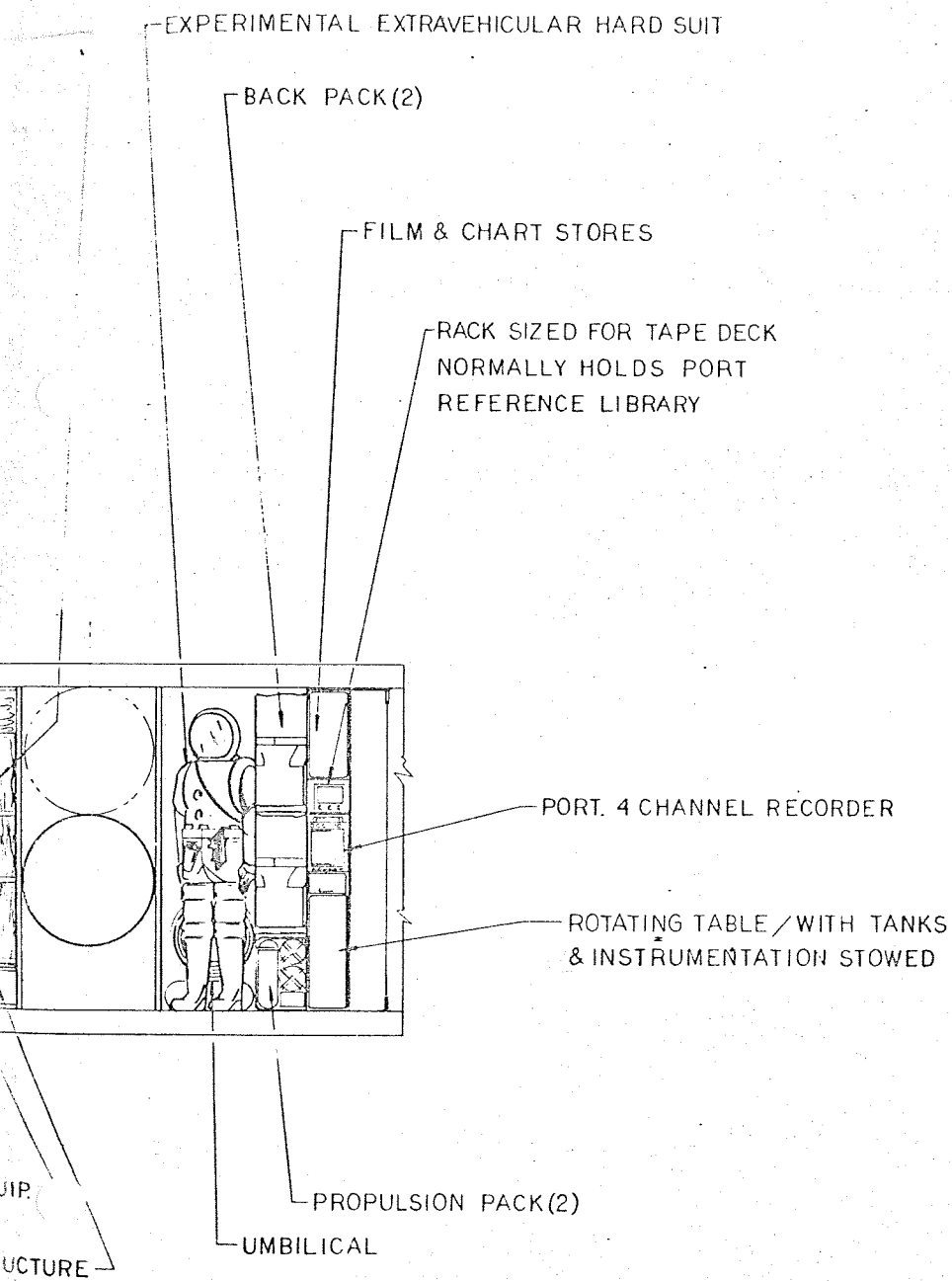
LR 18906

FIG. 2-69

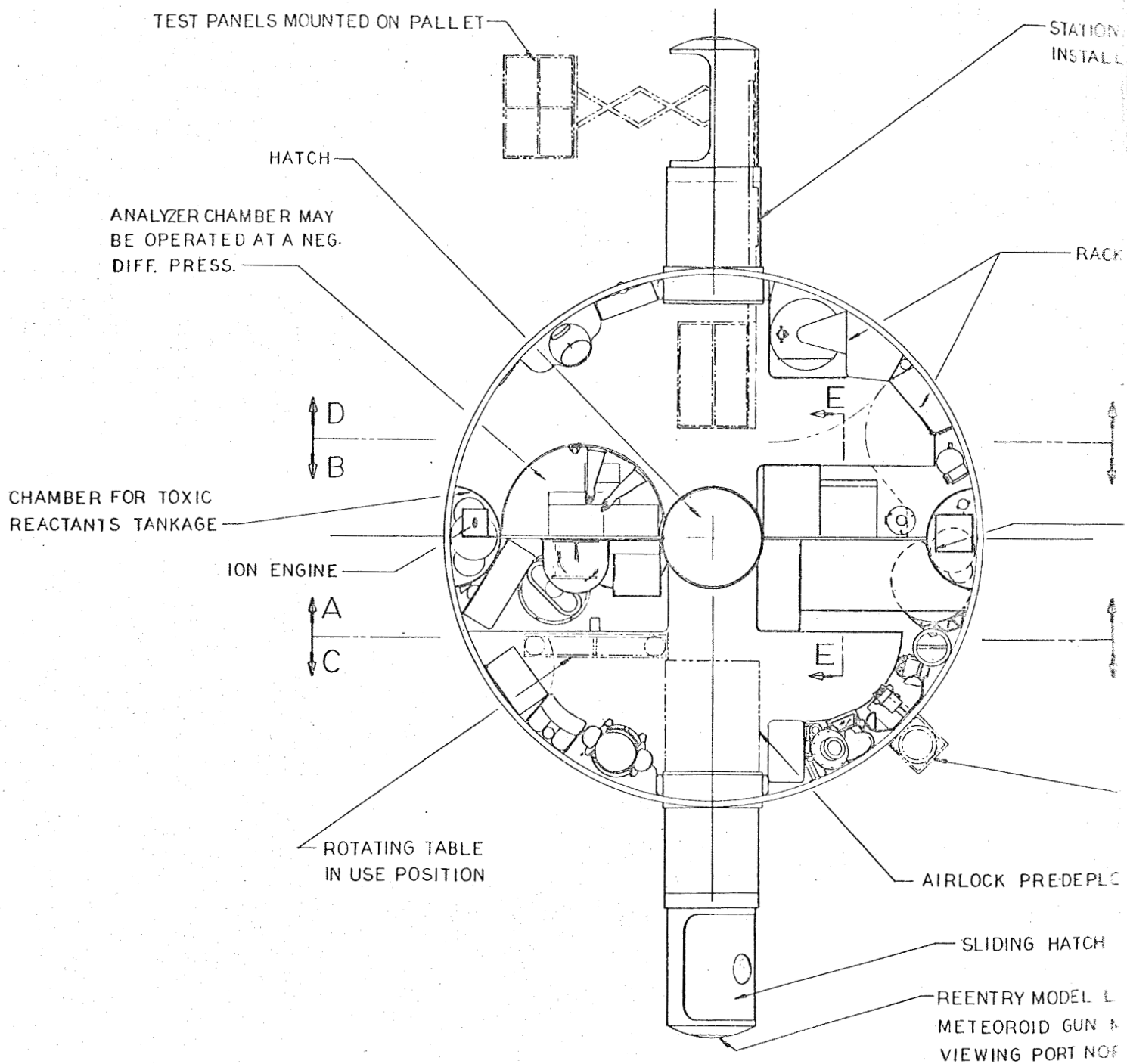


SECTION D-D





SECTION C-C



PLAN VIEW

STATIONARY PART OF PALLET RAIL IS
INSTALLED AFTER AIRLOCK DEPLOYMENT

RACKS MAY BE SWUNG AWAY FROM WALL

COLD TRAP

SHADOWGRAPH EQUIPMENT
FARADAY CUPS, & ANALYZERS

FLAMMABILITY CHAMBER CONTROL

FLAMMABILITY CHAMBER
(INTERCONNECTED WITH
ANALYZERS THRU WEB)

SPECTROGRAPH

FILM & CAMERA

HYDRODYNAMIC JOURNAL PACKAGE

SHIELD

TEST FRAME IN VACUUM
CHAMBER BULKHEAD

SPHERICAL DISTILLATE DEVICE

PROTECTIVE GLASS

BUBBLE CHAMBER

CENTRIFUGE

HELMHOLTZ COILS INSTALLED

FLUID INTERFACE MONITOR

BEARING TESTS (2)

CLOSED LUB SYSTEMS (3)

COMBUSTION MATERIALS

FLUID INTERFACE TEST ASSY

POWER SUPPLIES

COATING

ION ENGINE IN

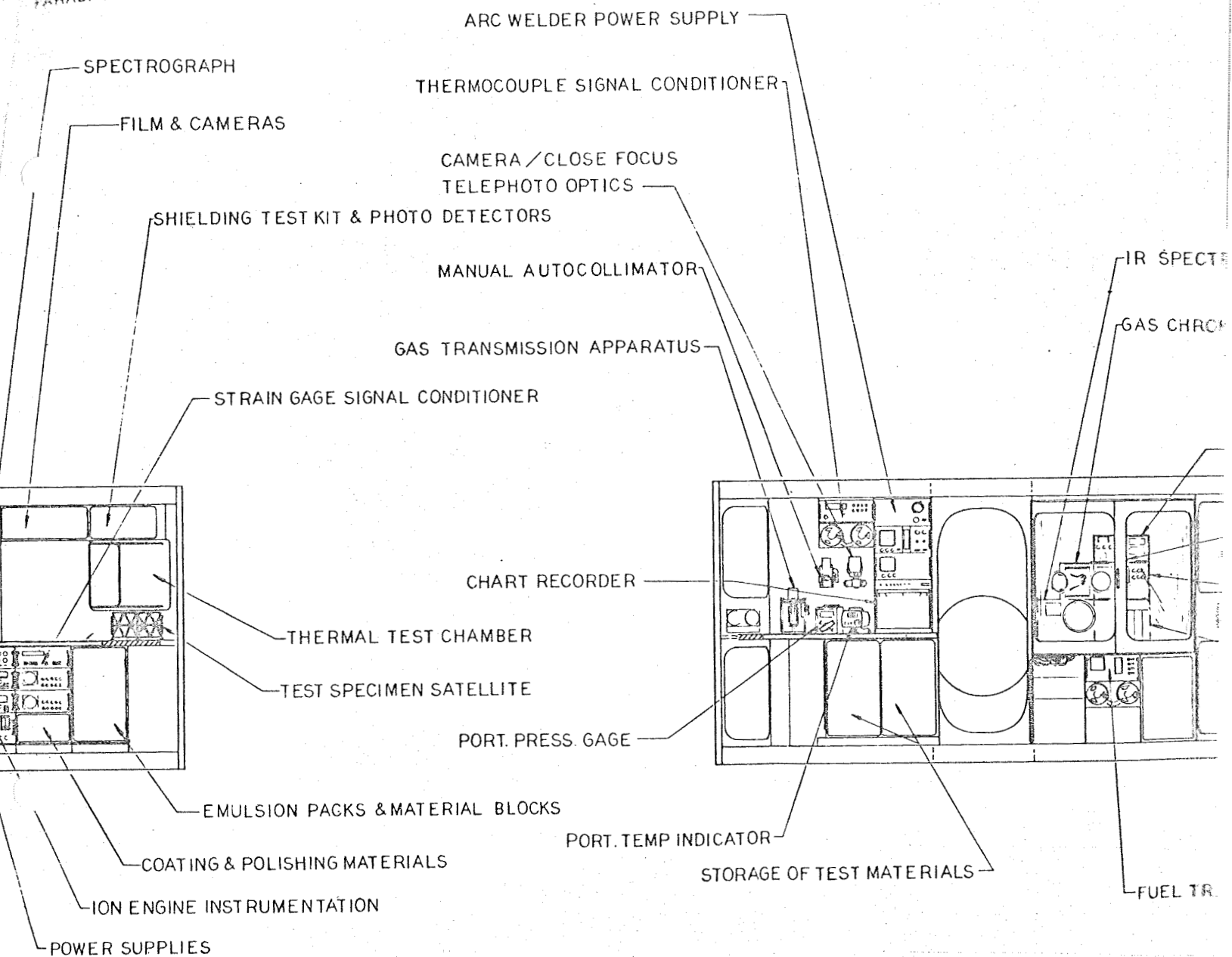
SECTION A-A

RE DEPLOYMENT

HATCH

MODEL LAUNCHER &
GUN MOUNT HERE
PORT NORM. MOUNTED

SHADOWGRAPH EQUIP., CONCENTRIC SPHERES
FARADAY CUPS, & MAGNETOMETERS



SECTION B-B

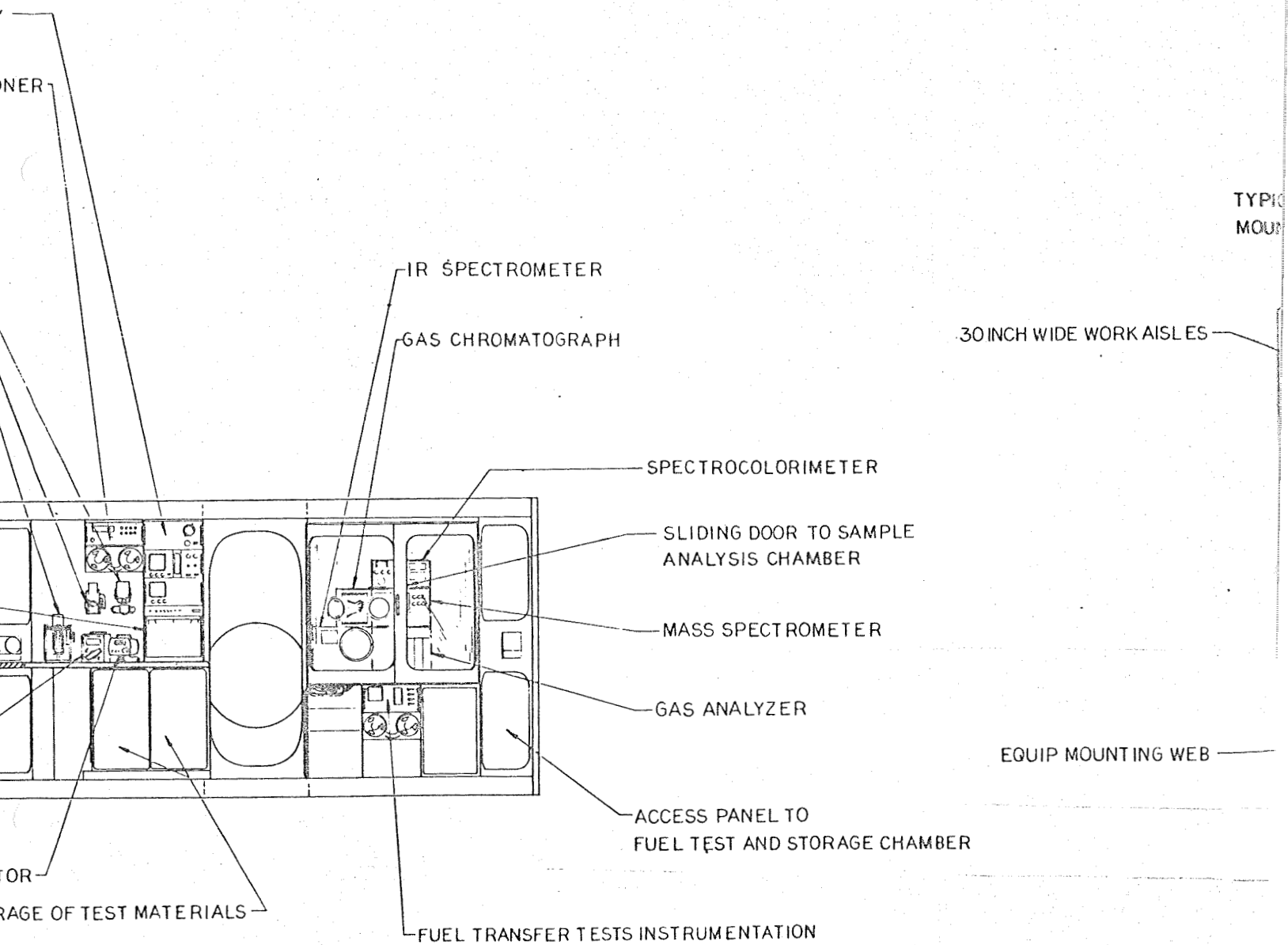
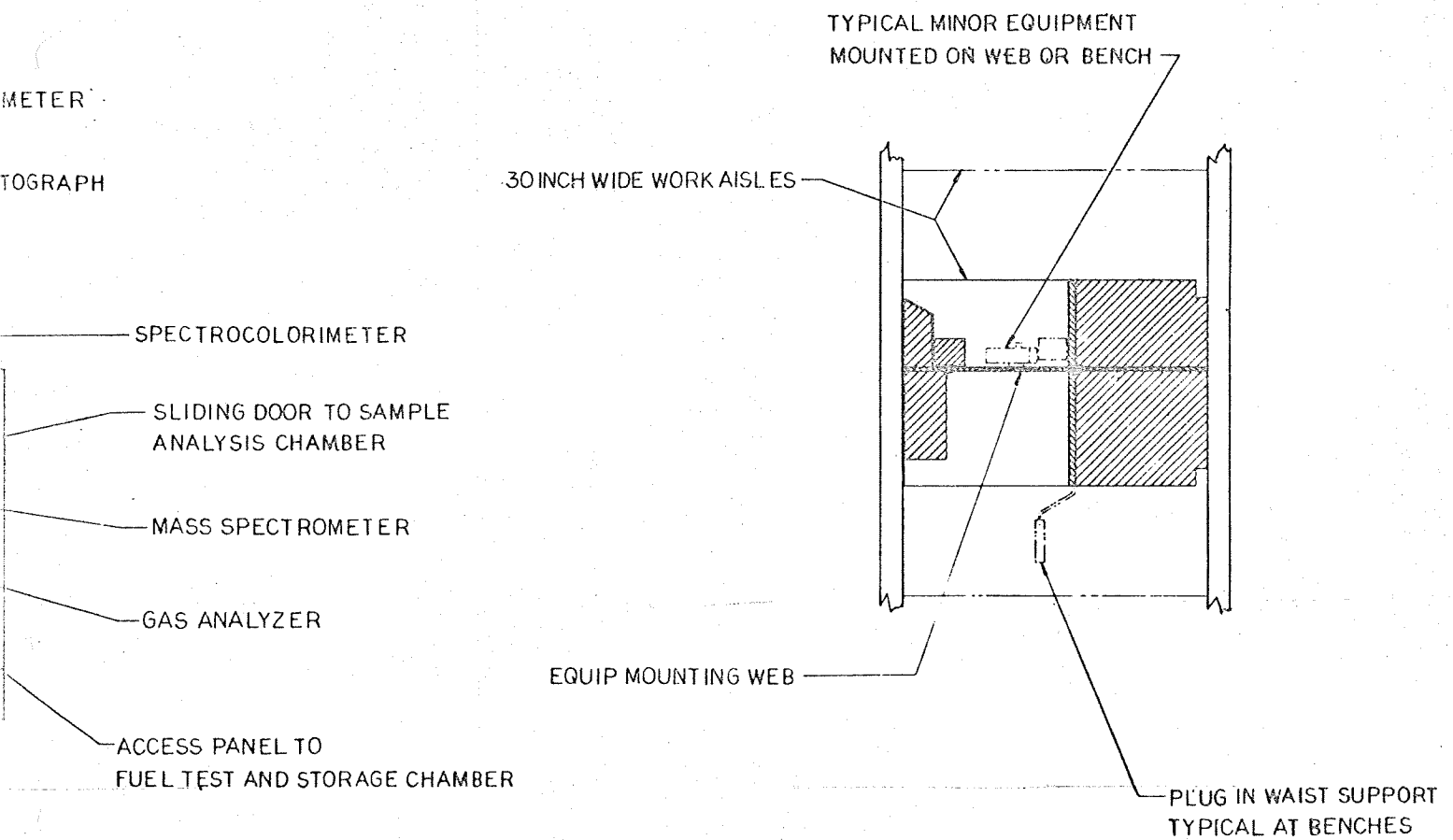


FIG. 5-28 INTERIOR ARRANGEMENT — PHYSICS LABORATORY

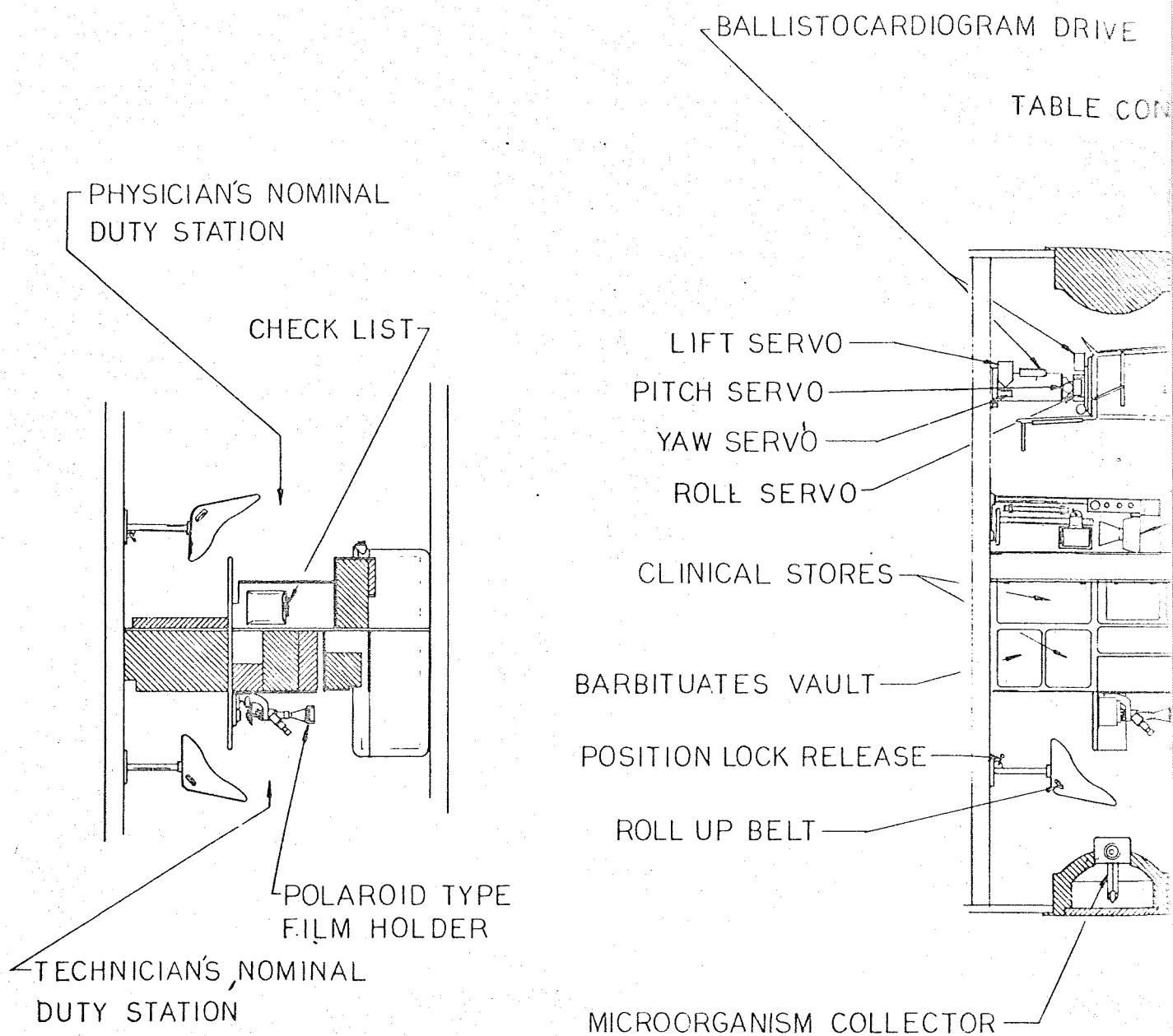


PER TESTS INSTRUMENTATION

SECTION E-E

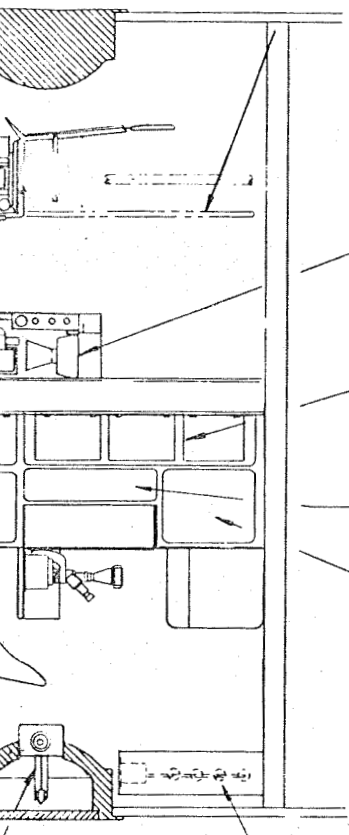
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FIG. 2-70



RIVE

LE CONFIGURATION



PORT. X-RAY
SET STOWED

POLAROID TYPE
FILM STORAGE

FIRST AID

DENTAL & CAST
SUPPLIES

CONTINUOUS CULTURE
ALGAE APPARATUS

ION A-A

SPACESUIT STOWAGE

ERGOMETER

WASTE STOWAGE

SLIDING DOOR

EXPER. FILM PROCESSING

DARKROOM CURTAIN

SPACESUIT STOWAGE

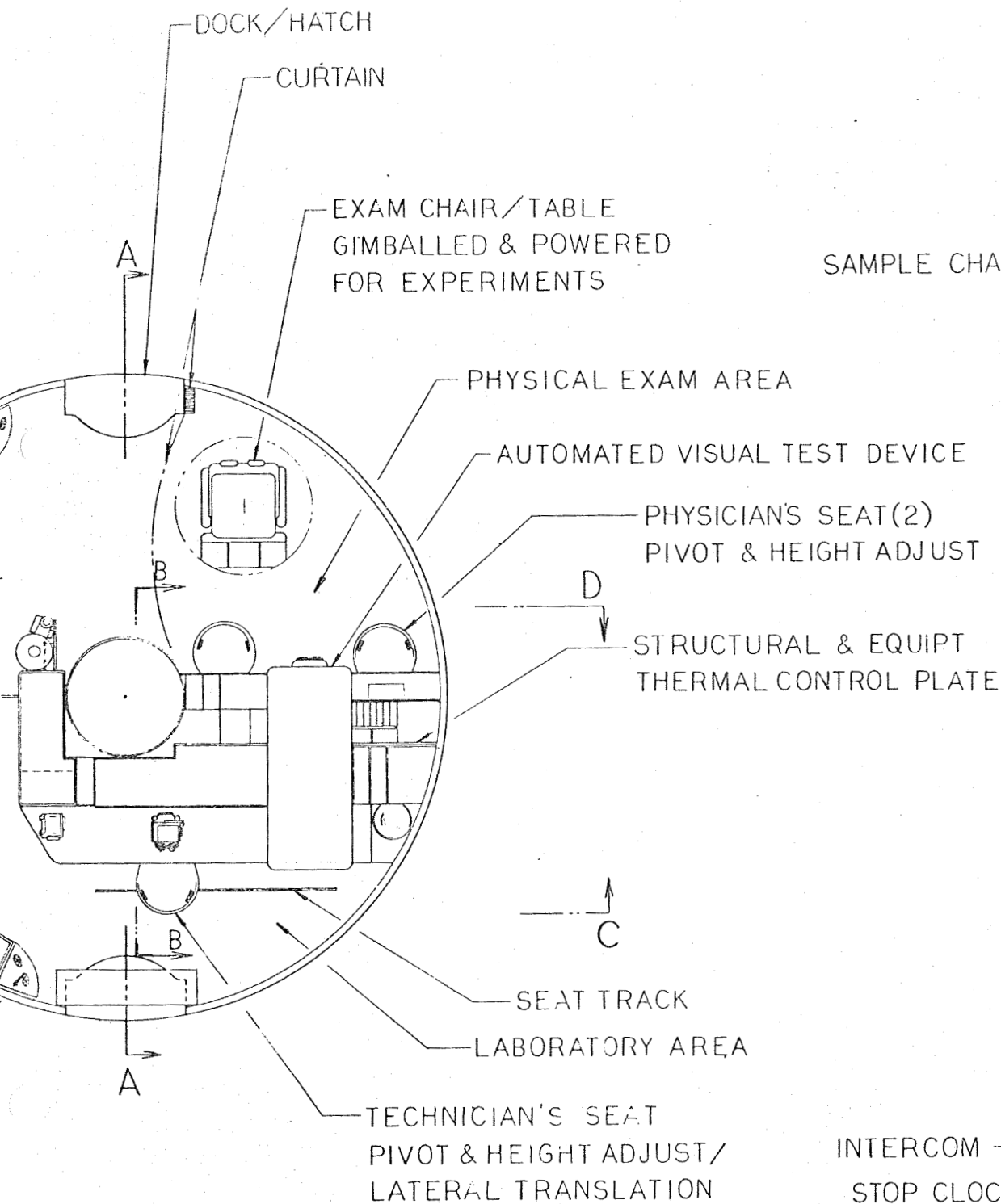
PLANT & ANIMAL STORAGE CONTAINERS

EXPERIMENTAL WASH FACILITY

D

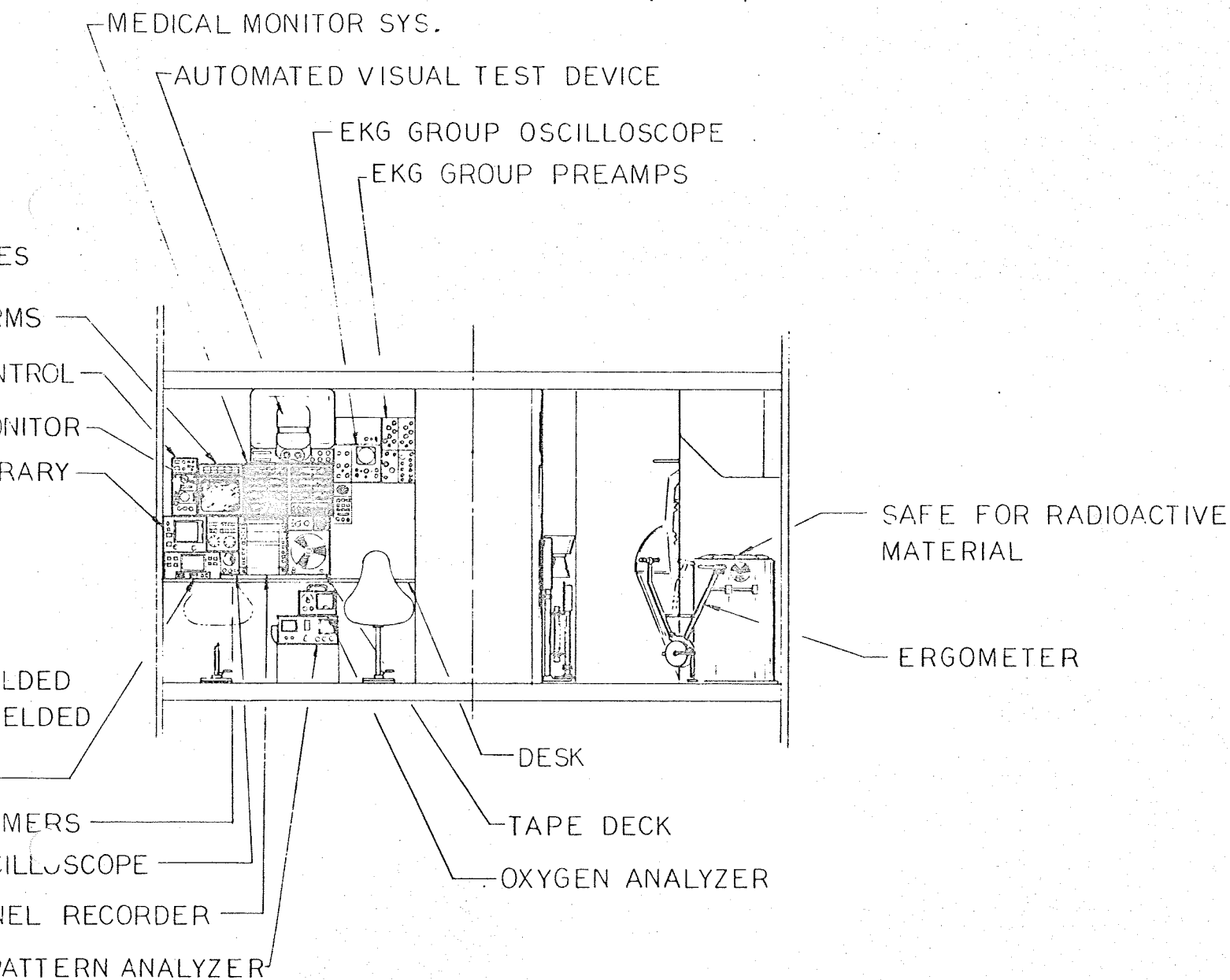
C

PLAN



CA
ANIMAL SAMPLE C
CELL
SAMPLE CHAMBER & TRANSFER AP
PRECISION GAS DETE
HEMO-DILU
SLIDE STORAGE
GAS CHROMATOGE
SCINTILLOMETER

INTERCOM —
STOP CLOCK —
ELAPSE TIME —
PRESS GAGES —
MASS SPEC



SECTION D-D
PHYSICAL EXAM AREA

FIG. 5-29 INTERIOR ARRANGEMENT — BIOMEDICAL LABORATORY

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the extra-vehicular experiments with the hard space suit shown in the right portion of Section C-C. Section C-C also shows life support and propulsion back packs in this area. The left portion shows tools, test equipment, and expandable and inflatable structures.

The stowage of experimental solar panels, satellite and checkout equipment, and algae culture containers is shown in section D-D.

Certain tests performed in this compartment require the use of fuels and oxidizers. These are stored in sealed compartments separate from each other and the cabin atmosphere; they are vented to the external environment.

This compartment has stowage space for one operational space suit.

5.4.4.2 Biomedical Laboratory

The biomedical laboratory for the Interim Modular Space Station is shown on Fig. 5-29. A perspective view of this compartment is shown on Fig. 5-30. The tests and equipment shown in this compartment are for the physical and medical testing of man, and biological testing of tissues and certain insects.

Section A-A of Fig. 5-29 shows the examining chair-table combination which is equipped to perform ballistocardiograms. Various stowage areas are shown to the right of the chair. A micro-organism collector unit is extended out through one of the universal hatches.

Section C-C shows the laboratory analysis area. In this area, analysis of samples is performed and slide preparation and microscopic examination is accomplished. To the left of this area is a stowed space suit that is actually on the far wall. Stowage for two space suits is provided in the compartment. The left portion of this section shows the experimental film processing area. A folding door around this area creates a darkroom.

Section D-D shows the physical examining area. Along with the electronic test equipment is an automated visual test device. To the right of the

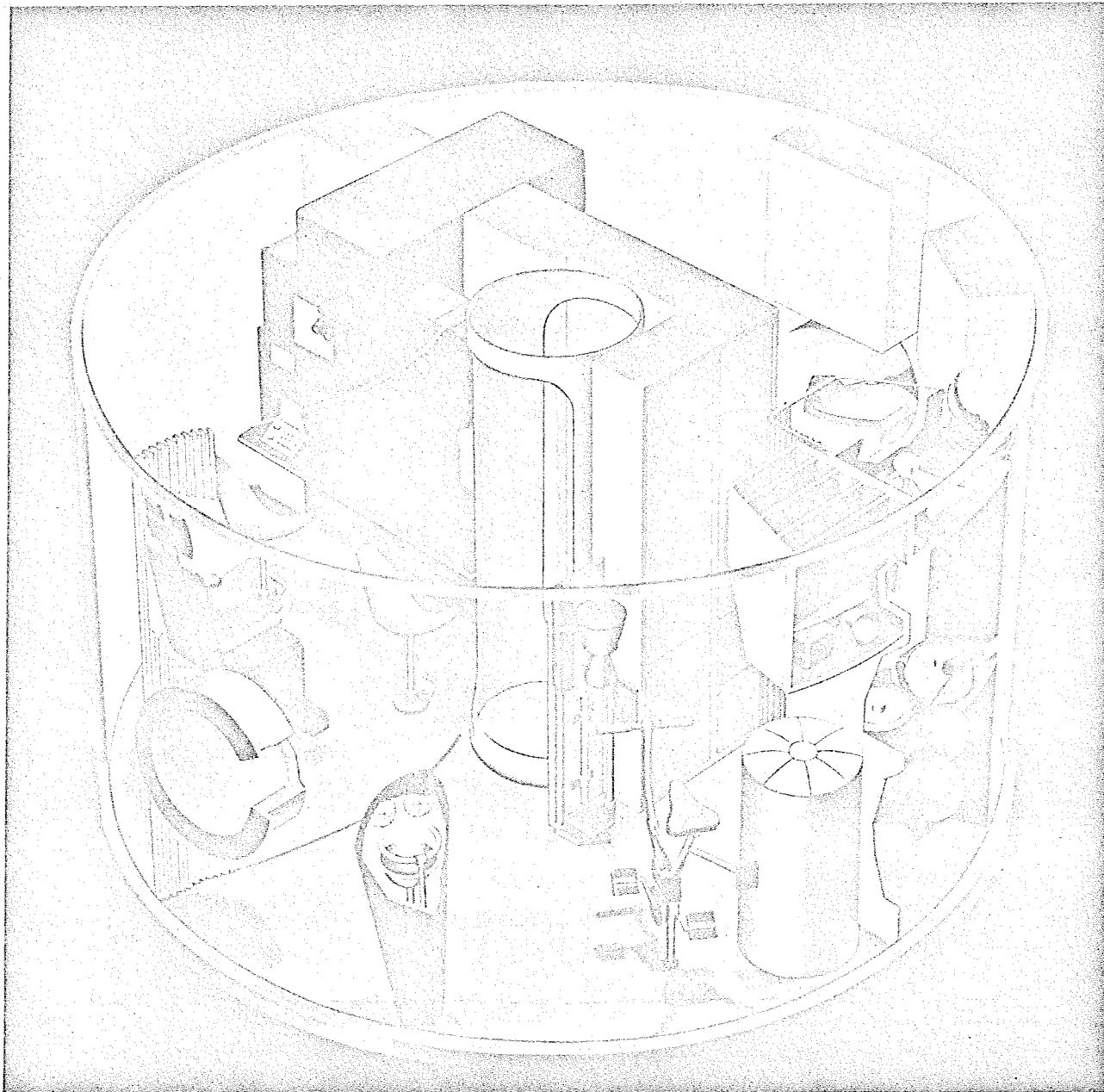


FIG. 5-30 BIOMEDICAL LABORATORY — PERSPECTIVE VIEW

interconnect tube is a stowed portable X-ray machine and beyond this is a bicycle ergometer which can be stowed when not in use. A safe for storage of medical and experimental radioactive materials is located behind the ergometer.

5.4.4.3 Observatory

The interior arrangement of the observatory is shown on Fig. 5-31. Being an observatory, a good portion of the sensors must have openings through the external pressure wall. The equipment is mounted against the wall but is quickly removable in case of necessity for puncture repair.

View A-A shows infrared and ultraviolet radiometers mounted on a stable platform located to view through windows. A camera is located above for data recording. Electronic consoles fill the next areas along with a computer and tape deck. To the right of center are the electronic components that are related to tests performed on the stable platform at the extreme right. Two film viewer stations are in this area. One is a direct viewer with a screen and the other is a stereo viewer. Storage as indicated is below this equipment.

View B-B shows a high-resolution telescope inserted in the universal hatch. The cabinets to the right house experimental equipment, gyros, etc. Film supplies and processing equipment are next in line. The free body test units are stowed in the next cabinets. They are small satellites that are checked out on the table at the right of the stowed space suit. Below the table is the stowed laser communications pod. The external hatch is used for the laser pod and is also used for the free body test units that are inserted into the hatch and picked up by the extendable probe. The probe is extended and the test unit is released into free space. Above the external hatch is a spotting telescope for use as a pointing aid for other optical equipment. The universal hatch has a twin camera telescope mounted in it. Directly above this is an infrared scanner. Film storage cases are mounted

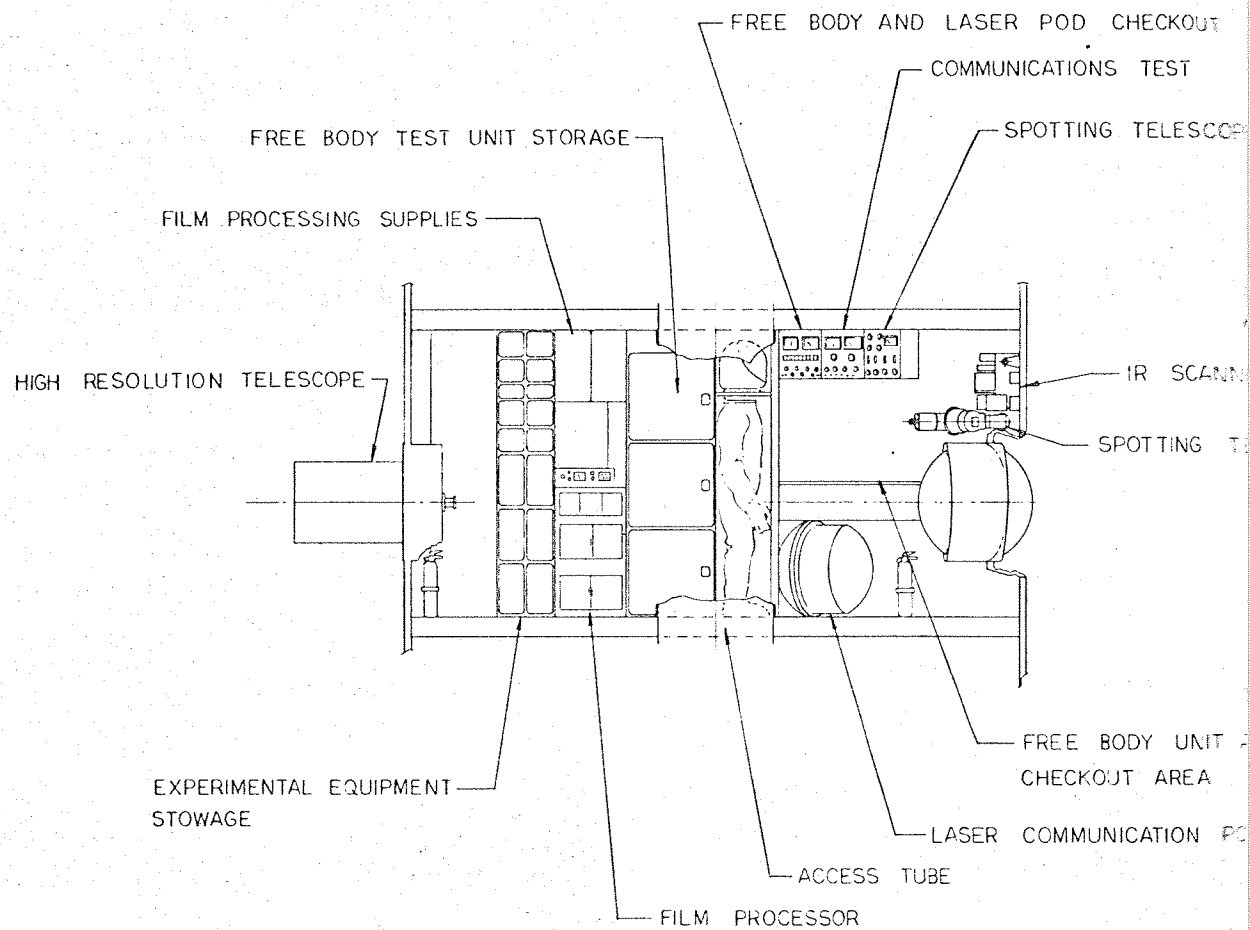
against the access tube interconnect in the center of the compartment. A bank of three disk antennas is mounted externally.

5.4.4.4 Control Compartment

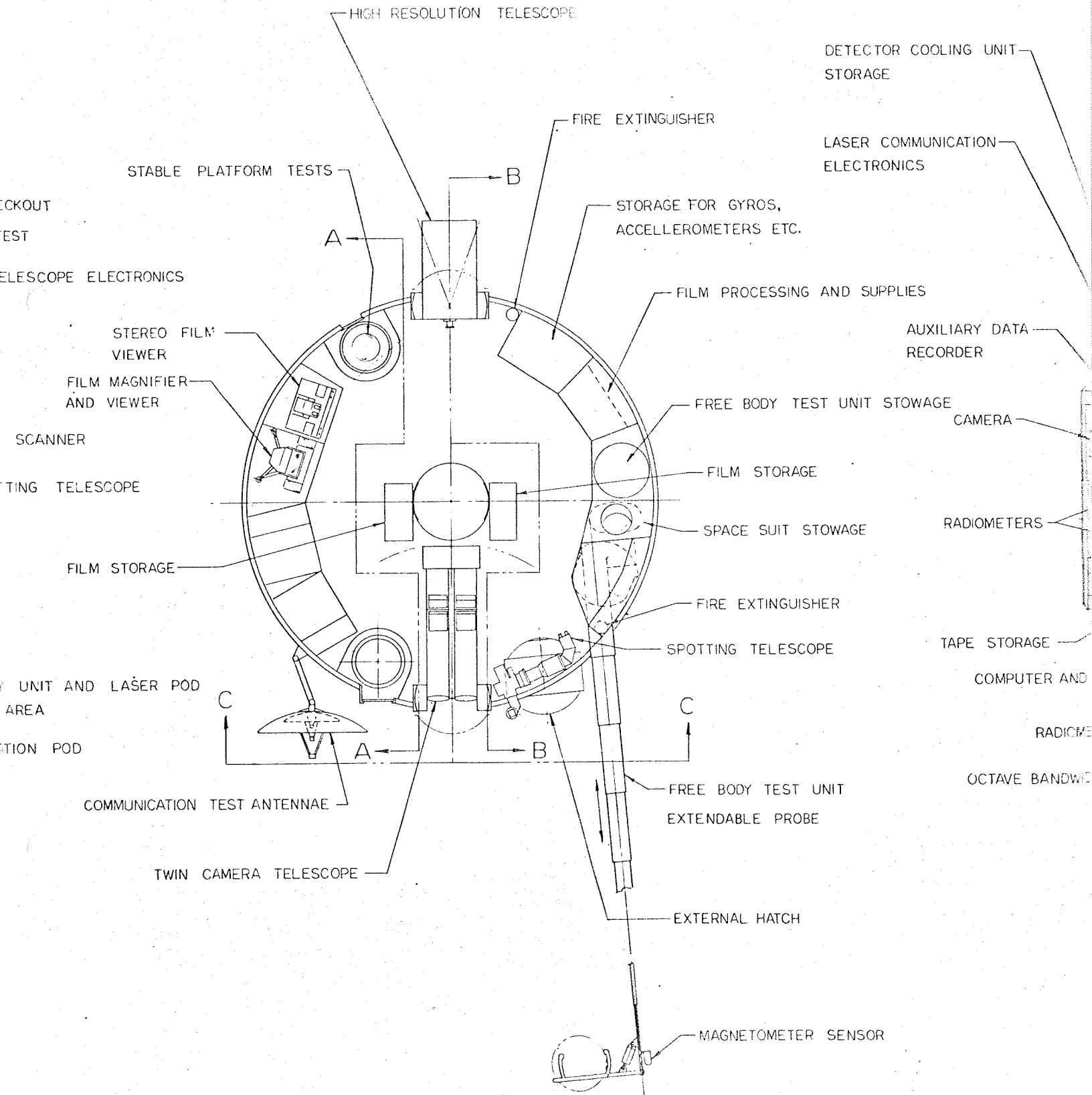
The control compartment as designed for the Interim Space Station is shown on Fig. 5-32. Three space suits can be stored in this compartment. View B-B shows the main control console from which decisions concerning the on-board subsystems are made. Communications are also handled from this area. The left side of view B-B shows the psychological testing area which can be closed off from the rest of the station by a folding door.

The left side of view D-D shows groups of electronic test equipment and recorders to tabulate results. The right side of this view has the experimental control console. Among experiments here is a simulated control console for the training of crew members in station operation. An external antenna is located in one universal hatch and the other hatch mounts a solar concentrator for use as an experimental source of electrical energy.

FIG. 2-68



VIEW B-B



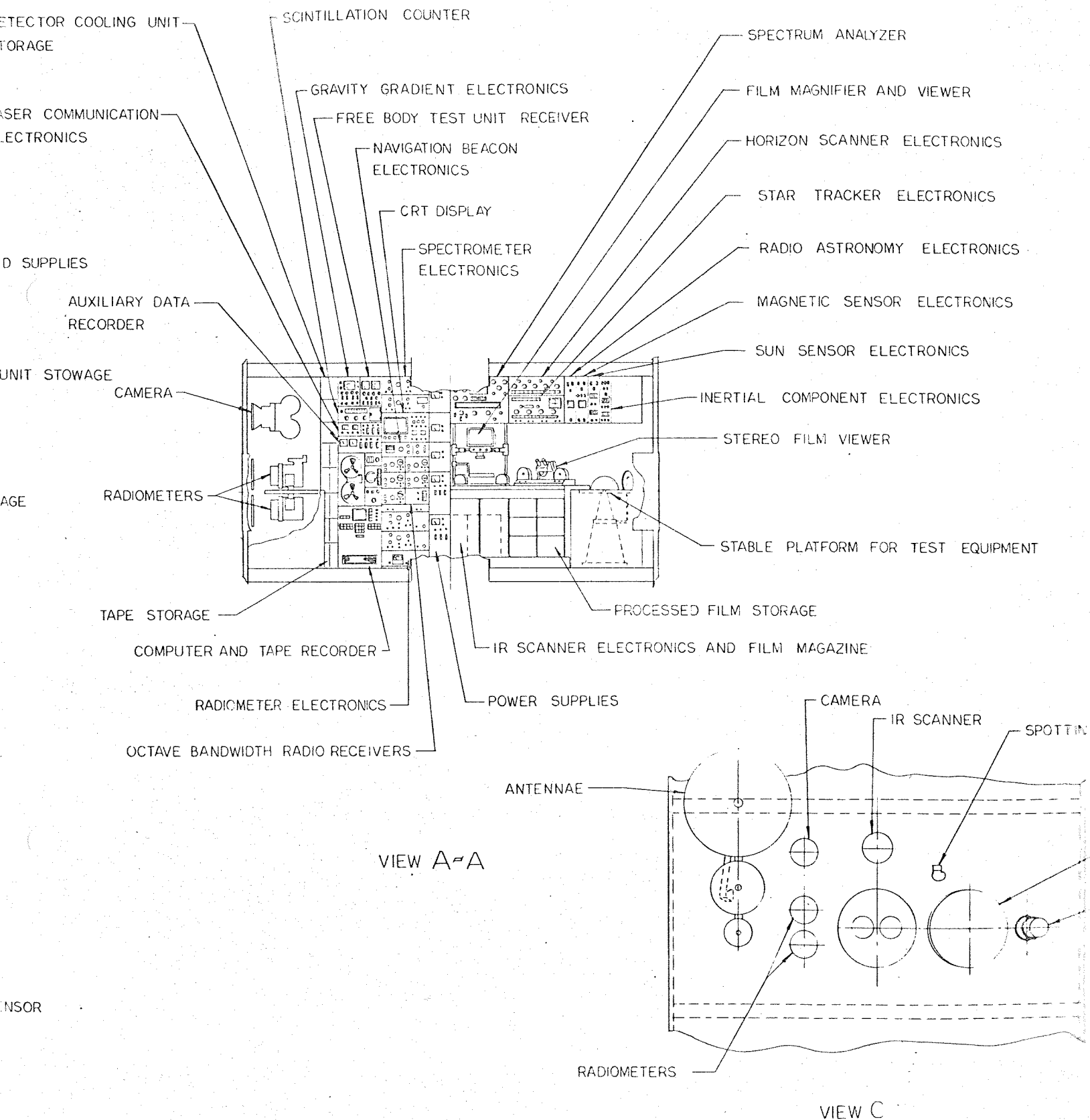


FIG. 5-31 INTERIOR ARRANGEMENT — OBS

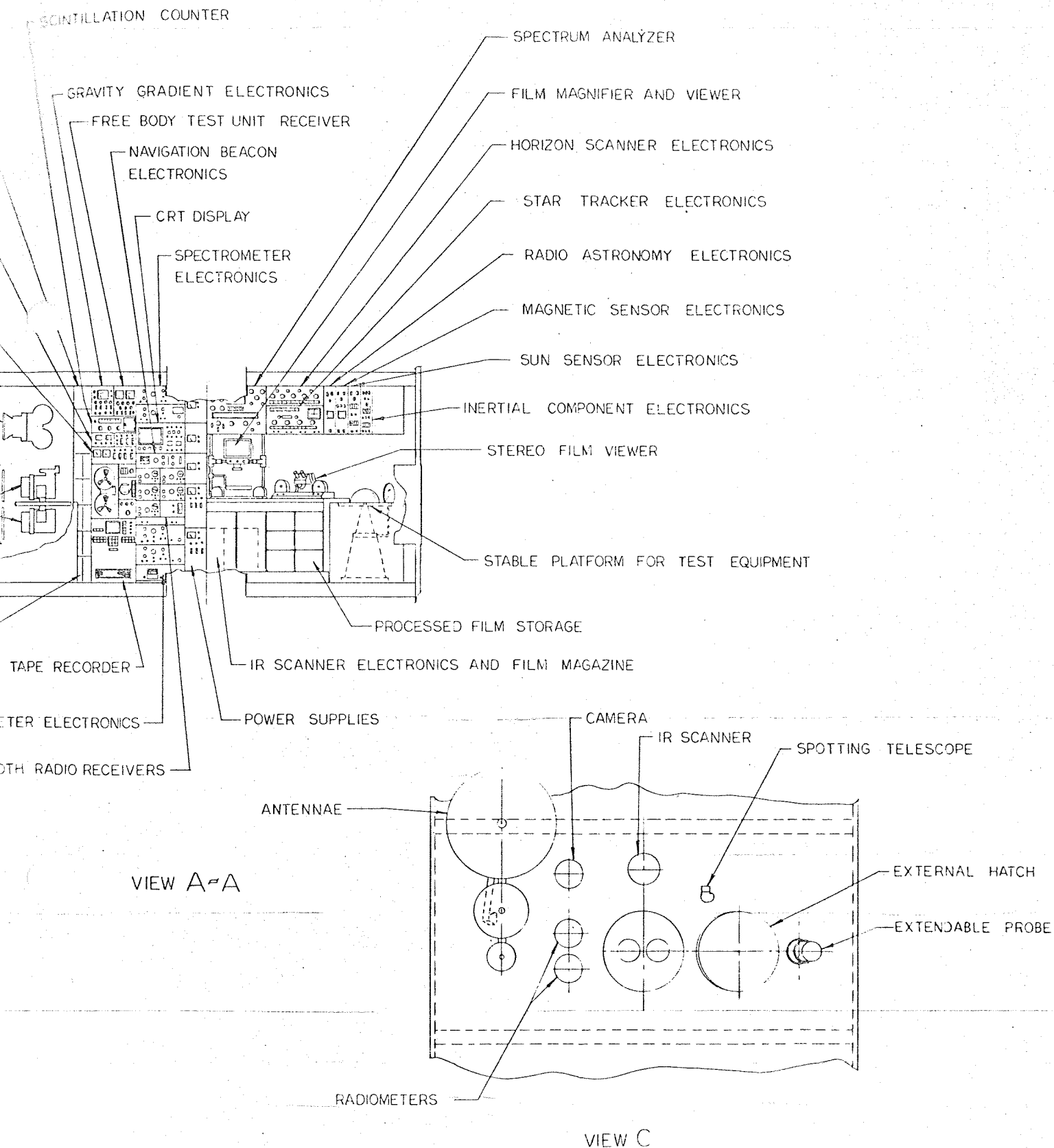
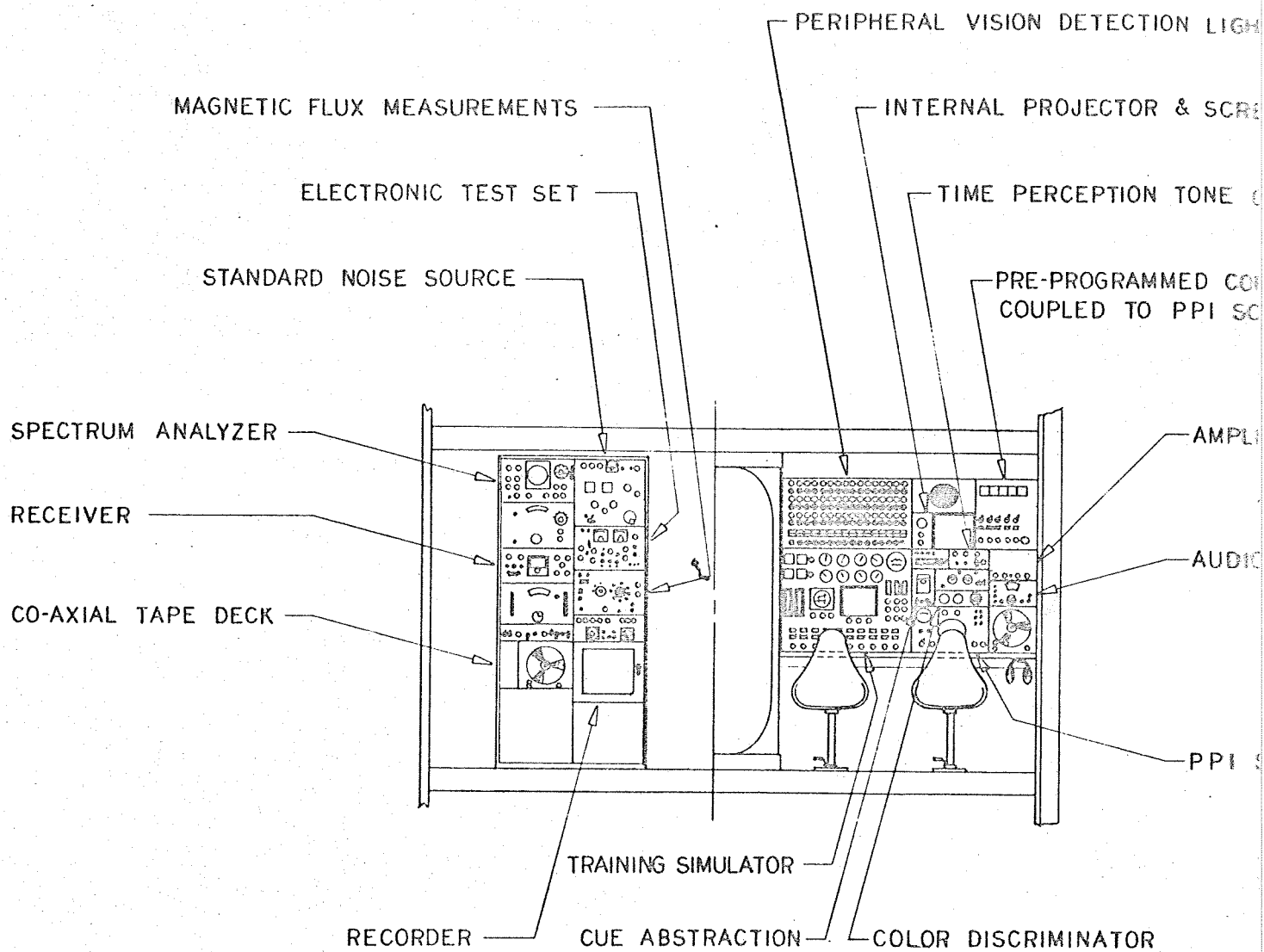


FIG. 5-31 INTERIOR ARRANGEMENT — OBSERVATORY

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FIG. 2-71



VIEW D-D

ATION LIGHTS

R & SCREEN

N TONE GENERATOR

MMED COMPUTER
D PPI SCOPE

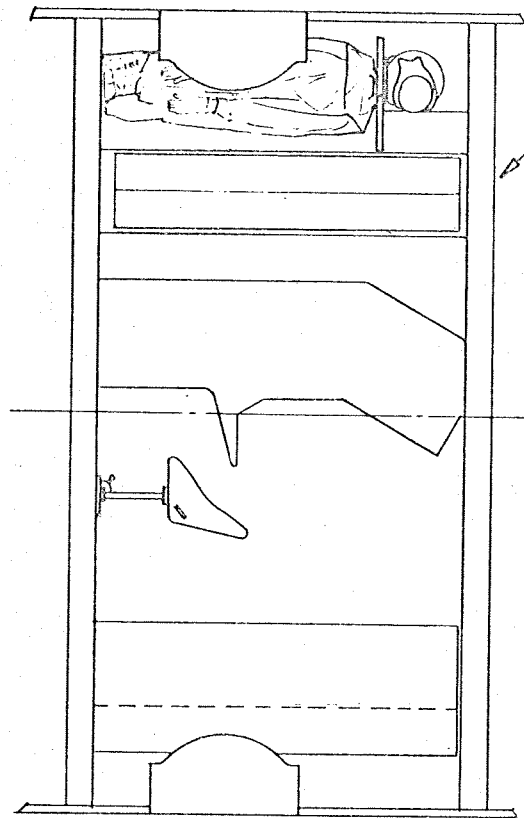
AMPLIFIER

AUDIO SIGNAL GENERATOR

PPI SCOPE

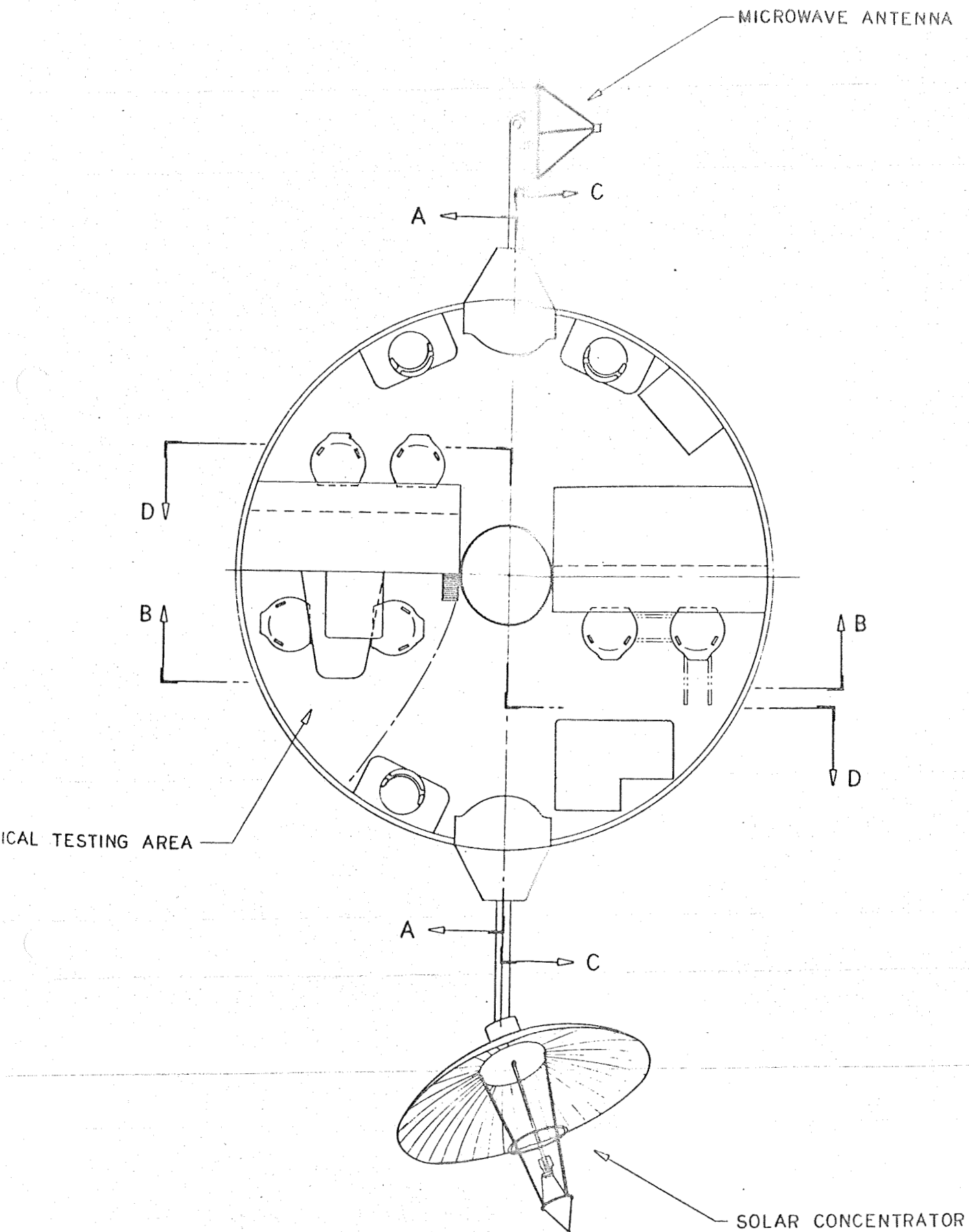
R

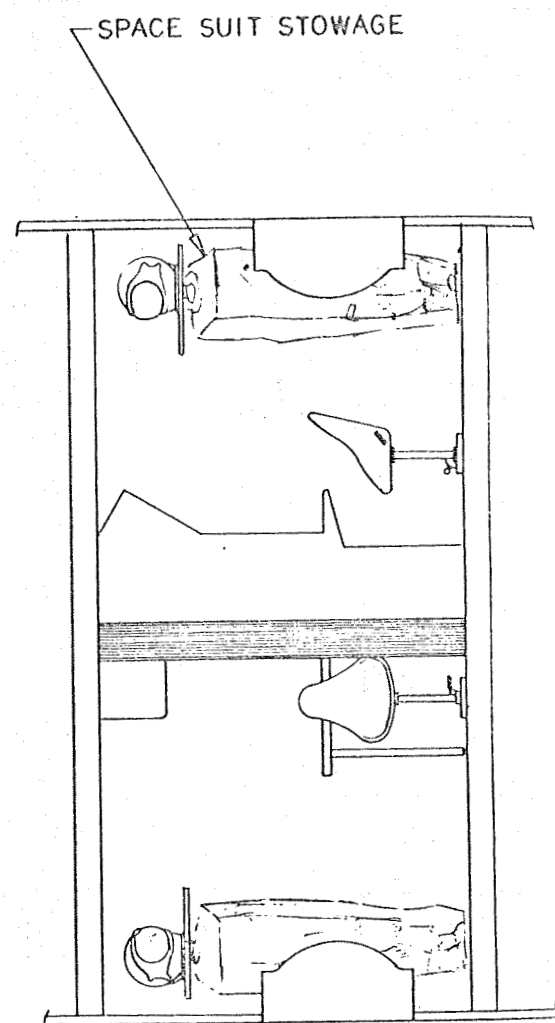
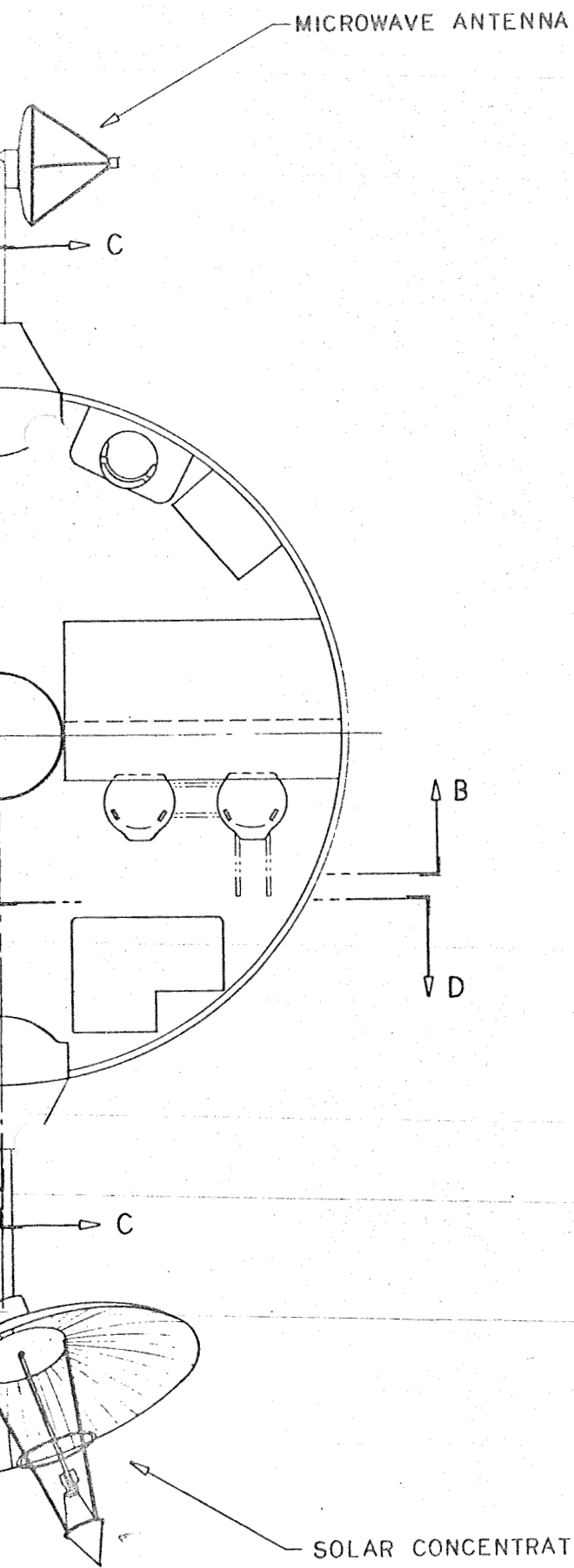
MISCELLANEOUS STORAGE



PSYCHOLOGICAL TESTING AREA

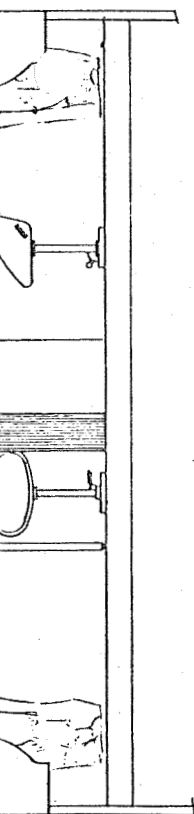
VIEW C-C





VIEW A-A

AGE



A

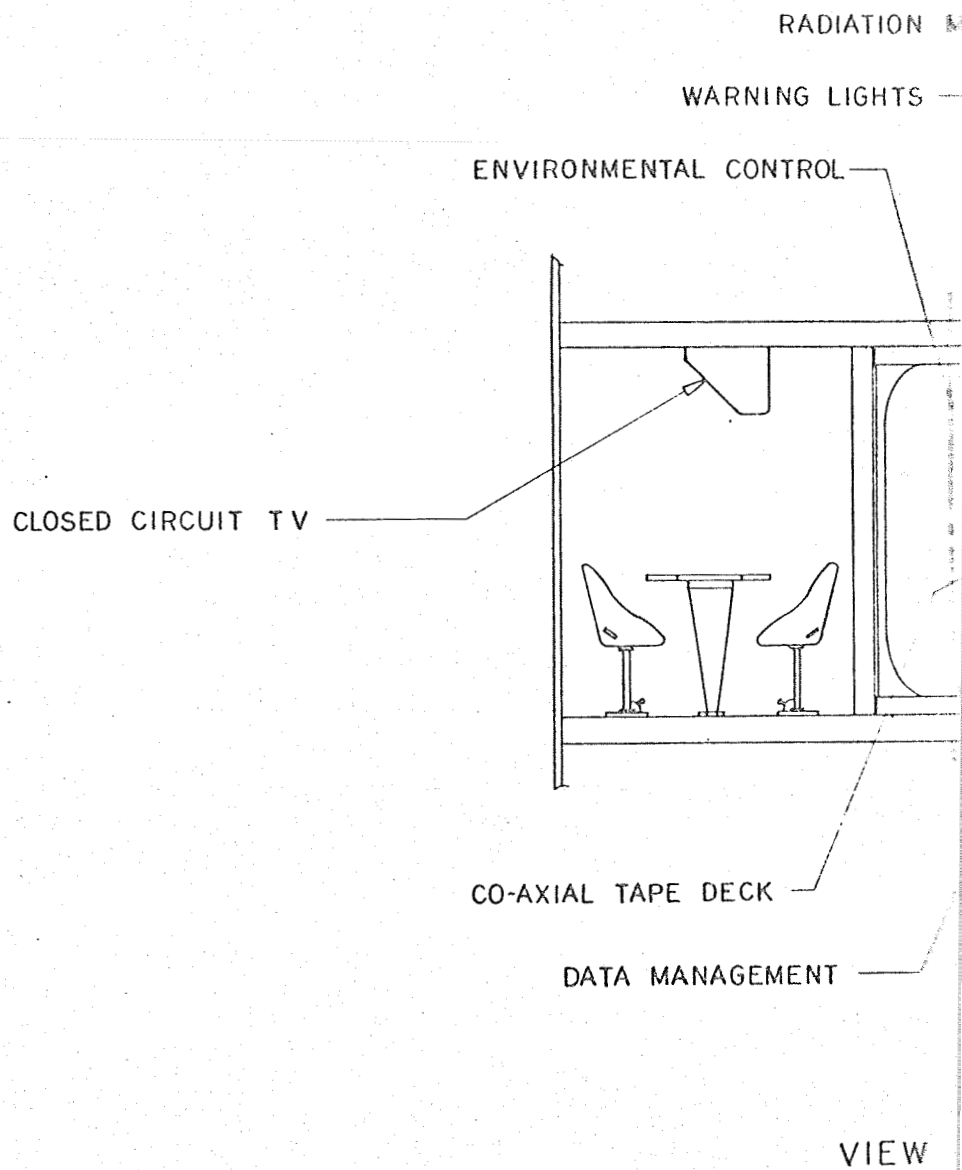
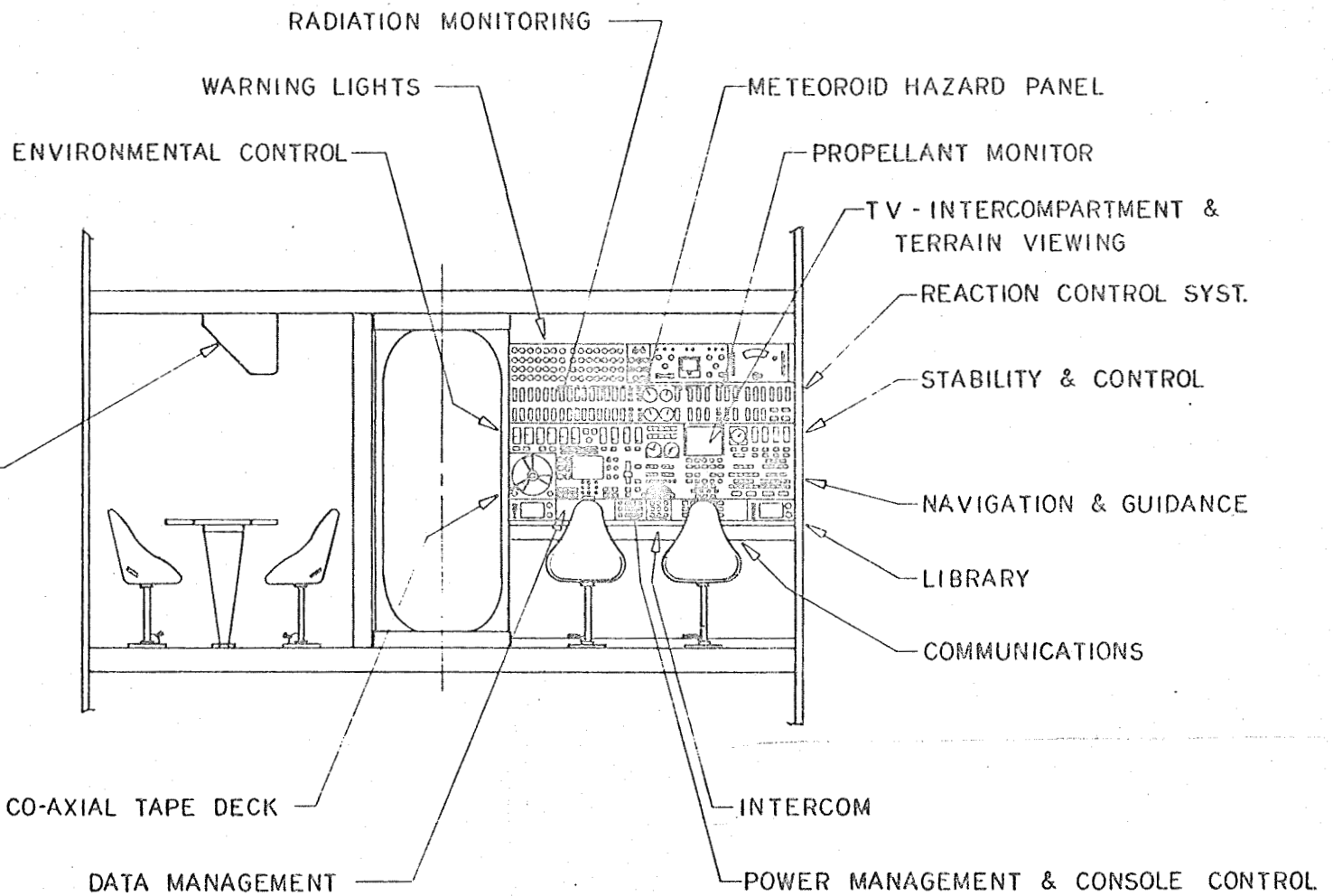


FIG. 5-32 INTERIOR ARRANGEMENT



VIEW B-B

FIG. 5-32 INTERIOR ARRANGEMENT — CONTROL COMPARTMENT

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5.5 SPACE STATION/APPLICATIONS INTERFACE

The effectiveness of an earth-orbiting laboratory or space station can be evaluated in terms of its ability to accommodate candidate experiments or perform the proposed applications. Section 5.2 has previously described the individual application requirements; these requirements as imposed on the laboratories/space stations, subsystems, and crew are summarized in the following section, and the capabilities of the Modular Multipurpose Space Station configurations to support and perform the applications are described.

5.5.1 Application Requirements

The individual application descriptions and requirements for this study are given in Section 5.2. For final integration into the space stations, the following requirements would be specified.

Orbit Altitude and Inclination. Orbit parameter requirements are the most exacting for the earth-oriented missions. Photographic missions, for example, can be enhanced by a lower altitude and higher inclination for increased resolution and coverage. Long duration missions can better be achieved at a higher altitude to offset drag and the resultant propellant penalties. Earth-to-earth communication applications dictate the use of a synchronous orbit. The numerous zero-gravity experiments have no particular orbit requirements.

Stabilization and Pointing. The space viewing applications impose the most severe requirements in terms of sensor apparatus stability and pointing accuracy. The severity of this requirement in many cases dictates the use of separately stabilized platforms and possibly the tethering of individual experiment packages. The disturbances due to station mechanical subsystems and crew movements is a subject for further detailed analysis.

Location and Access. Particular experiments have specific location requirements by nature of the performance required, e.g., internal or

external to the station or experimental subsystems in the subsystems compartment. Others can be located only after detailed station layouts are created to minimize crew movements and to optimize station volume utilization.

Windows. Special design problems are created when remote sensing of data must be accomplished by apparatus located within the station. Optical and thermal distortions and filtering effects must be constantly evaluated to insure experiment performance satisfaction. Two universal hatches are provided in each compartment; every effort should be made to locate experiments requiring access to space so that these hatches can be used.

Shielding. Individual equipment may require protection from space environment radiation, thermal radiation and subsystem electromagnetic interference in addition to the shielding effects of the station structure and installed equipment. Shielding of the crew from space environment radiation effects will be a more significant problem in some orbits.

Test Equipment. The individual experiments require supporting test equipment which in some instances is duplicative with other experiments. A further detailed study of the test equipment would result in some reduction in the experiment weight requirements.

Pre-requisite and Simultaneous Experimentation. The value of particular experiments is directly related to other experimentation or measurements being performed. Mapping applications, for example, will be enhanced by accurate time and position information and the development testing of such equipment should be given precedence. Biomedical experiments are often inter-related, the data from one experiment contributing to the value of a subsequent one.

Power. Electrical power is required for experiment warm-up, standby, and normal operation. Individual experiment power profiles must be prepared which can be scheduled for efficient utilization of the station power. Power requirements will be stated in terms of voltage and

voltage regulation, frequency regulation (where applicable), amperage, and total energy. Start-up and other load transients and their effects on other subsystems and experiments must be considered.

Environment. Environmental requirements of the experiments are generally not severe. A few experiments, employing sensitive sensors, require special low temperatures or precise temperature control. Atmosphere composition and pressure are critical principally to the experimenter.

Data Collection and Handling. The applications must be defined in terms of information sensed, rate of sensing, and quantity of data to be stored, processed or transferred by the data management subsystem. Information to be displayed must be determined and the related monitoring requirements assessed to avoid excessive demands being imposed upon the crew.

Experiment Duty Cycle. The maximum utilization of crew time for experiment performance is a basic mission objective. Accordingly, this can be accomplished only if the exact time and action requirements of each experiment are specified in advance. Complete descriptions of the steps to be performed in each experiment are required along with the time increments associated with each. The complexity of achieving optimum crew time utilization requires computer solutions.

Crew Skills. The value of an experiment in many instances will be proportional to the skill and technical background of the observer. Each experiment and application should suggest in its description the type of observer who would be knowledgeable of the subtleties of the phenomena observed.

5.5.2 Mission Capabilities

Mission capabilities of the Modular Multipurpose Space Station configurations are given in Table 5-23. The low inclination orbit missions are supplemented by 'special missions', the polar and synchronous, which give respectively increased global coverage and increased communication capabilities. Other special mission orbits, such as translunar, circumlunar and maximum elliptic out of the plane of the

Table 5-23
LABORATORY/SPACE STATION MISSION CAPABILITIES

Item	One		Two		Two		Interim		Operational	
	Compartment Dependent Laboratory	Compartment Independent Laboratory	Compartment Polar Laboratory	Compartment Synchronous Laboratory	Compartment Polar Laboratory	Compartment Synchronous Laboratory	Modular Space Station	Modular Space Station	Modular Space Station	Modular Space Station
Orbit Inclination, (deg.)	28.5	28.5	90	30			28.5	29.5		
Orbit Altitude, (n. miles)	200	200	200	19,380			200	260		
Orbit Maintenance	No	Yes	Yes	Yes			Yes	Yes		
Mission Duration, Months	1.5	3-12	3, Nominal	3, Nominal			12-60	60-120		
Resupply	No	Yes	Optional	Optional			Yes	Yes		
Crew Size	3	6	3-6	3-6			6-9	24-36		
Pressurized Volume, (ft ³)	1250	2500	2500	2500			7500	69,530		
Experimental Payload, (lb)	3300	*8080	1560	10,470			*41,000	*67,620		

*Initial Launch plus Required Logistic Launches for Normal Operation

ecliptic are distinct possibilities, but are not analyzed in this study. The payload available for experimental equipment is based on the nominal mission durations; the variation in payload available with change in mission duration is illustrated in Section 3.4, Weight Analysis. The volume available for experiments and applications is more difficult to assess. The gross pressurized volume must be reduced to account for necessary living, aisle, and subsystem space requirements. A compartment devoted entirely to experimentation could be expected to achieve a maximum of 60 to 65 percent volume utilization. Compartments combining experimental and operational functions would correspondingly obtain lesser volume utilization.

The capability of the modular laboratory and space station subsystems to provide necessary experiment inputs and conditions can be ascertained from the Subsystem Specifications, Section 4.2. Brief discussions of the subsystem and crew support of experiments are given in the following paragraphs.

Environmental Control and Life Support. Environmental Control Subsystem support of Modular Multipurpose Space Station experiments and applications normally consists of providing heating, cooling, pressurization, and contaminant removal. Special sensor and detector cooling will be provided by independent cryogenic subsystems that must be considered as part of the experimental equipment. The extent to which these functions can be accomplished and controlled are stated in Section 4.2.1. Performance of the Environmental Control Subsystem generally affects the experimenter more directly than it does the physical experiment apparatus; experiments requiring precise temperature control for dimension stability are an exception.

Electrical Power. Electrical power for experiment operation is provided in the form of regulated and unregulated direct-current power and alternating-current power to the tolerances given in Section 4.2.3. The design approach is to distribute this power throughout the stations on a central bus; experiments requiring additional voltage or more precise

power characteristics must provide their own conversion or regulation components. Power available for experiments ranges from 0.4 kw for the One-Compartment Laboratory to 10 kw for the Operational Modular Space Station.

Communications, Command and Tracking. The Communications, Command, and Tracking Subsystem will have the capacity to transmit to the ground the required quantities of experimental data consistent with the coverage obtainable with the anticipated ground communications network of receiving stations. Considerable data compaction must have taken place previously either manually or in the Data Management Subsystem.

Data Management and Displays. The Data Management and Displays Subsystem will provide the necessary monitoring, storing and displaying of experimental data. Because the experimental data quantities need to be further defined, the required subsystem capacity is difficult to predict; the data handling capacity of the subsystem as currently estimated is given in Section 3.4.4.

Navigation and Guidance. The Navigation and Guidance Subsystem will provide station position and time correlation to support earth and space observations. In addition, a local vertical reference will be established to provide a basis for Stability and Control Subsystem determinations of station attitude. The accuracies to which these parameters are expected to be measured are stated in Section 4.2.6.

Stabilization and Control. The Stabilization and Control Subsystem will provide station orientation data; the magnitude of station and experiment pointing accuracies obtainable are given in Section 4.2.5. Reduction of station accelerations will be accomplished in support of those experiments requiring zero gravity data. Angular drift will be controlled within tolerances stated in Section 4.2.5 by use of reaction jets and momentum exchange wheels.

Crew. The crew sizes vary from 3 (One-Compartment Dependent Laboratory) to 36 (Operational Modular Multipurpose Space Station). The manhours expected to be available per crew member is a function of the amount of

station operational duty required. An increase in station size generally reduces the individual time requirements for non-experimental activities. An estimate of experimental manhours available with varying crew size is shown in Fig. 5-33.

Original study scheduling of experiments (Section 5.4) hypothesized that three different skills were available from the crew, i.e., 'physician', 'physical scientist', and 'biomedical scientist'. Later examination of experiments showed the advisability of having some very specialized personnel in the physical sciences area, such as astronomers and atmosphere physicists on board the laboratories and space stations. The matching of crew skills and experiment requirements is a task for future study.

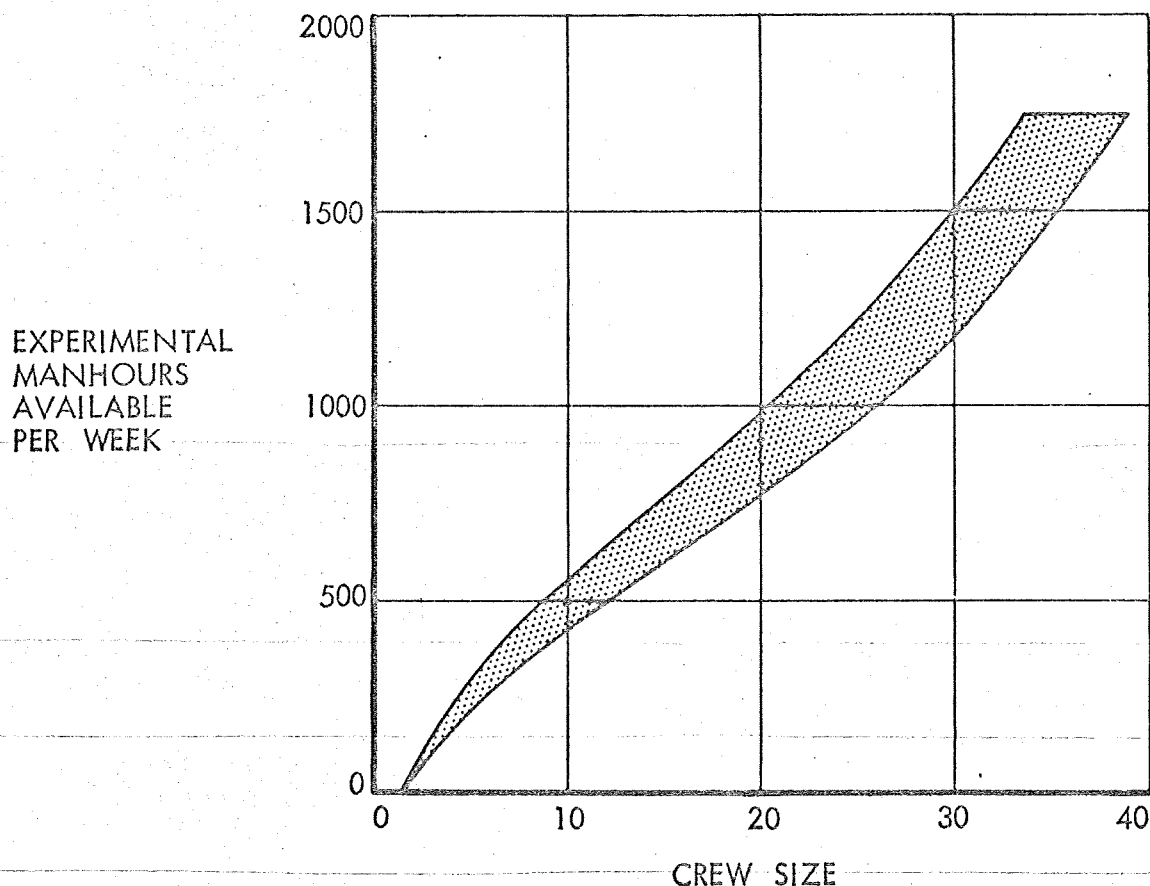


FIG. 5-33 EXPERIMENTAL MANHOUR AVAILABILITY AS A FUNCTION OF STATION CREW SIZE

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Section 6

DEVELOPMENT PLAN

The development plan for the Modular Multipurpose Space Station includes schedules with principal milestones and program costs in the NASA-suggested format for each space station configuration. Other development planning items, such as manufacturing, facilities, and transportation, are generally similar to those covered in other NASA studies and are not repeated in this conceptual study.

The quantity requirements of each configuration can be estimated only after an approved mission task model is produced and analyzed. As a result, the schedules and cost estimates are based on the development of one flight article in each configuration. Wherever possible, maximum advantage is taken of the modular or sequential growth; consequently, the development and test schedules and costs are sharply reduced in the later configurations. All basic subsystem development and test is accomplished for the Two-Compartment Independent Laboratory, and this effort is reflected in both the schedule and the development costs.

The development schedules are based on a nominal launch schedule suggested by the Manned Spacecraft Center. These launch dates are:

One-Compartment Dependent Laboratory	-	1970-71
Two-Compartment Independent Laboratory	-	1972-73
Interim Space Station	-	1974
Operational Space Station	-	1976-80

This launch schedule requires some schedule overlap between the flight of each vehicle and the succeeding configuration; however, the schedule overlap is never serious enough to preclude the incorporation of design improvements resulting from flight experience.

6.1 DEVELOPMENT SCHEDULES

The overall development schedule for the Modular Space Station program and its relationship to the Apollo Extension System is shown in Figure 6-1. Each of the four individual vehicle schedules is then presented in greater detail, and the subsystems and development articles are described in the following paragraphs.

6.1.1 One-Compartment Dependent Laboratory

The One-Compartment Dependent Laboratory development schedule, Figure 6-2, begins with a program definition effort which encompasses the total modular space station program.

This laboratory is dependent primarily on the subsystems in the Apollo spacecraft, hence, the development effort is confined largely to the module structure and the extension of the Apollo subsystems to accommodate the longer laboratory missions and the extended volume of the combination.

6.1.1.1 Structure

Structural development effort is extensive on this module since the structure must be flight rated for the severest load conditions anticipated for the succeeding configurations. Loads analysis and structural testing on this module will therefore include all basic loads for each configuration as well as fatigue, acoustics, vibration, shock, and the various materials tests designed to insure compatibility with the space environment.

6.1.1.2 Environment Control and Life Support Subsystem

Environmental control and life support is dependent basically upon the equipment in the Apollo command and service modules; however, this equipment must be supplemented for module thermal and atmospheric control and it must be increased in capacity for the 45-day mission. This requirement for increased environmental control subsystem capacity will be met by the use of additional units of the basic Apollo subsystem. Equipment repackaging and installation in the laboratory compartment will be necessary.

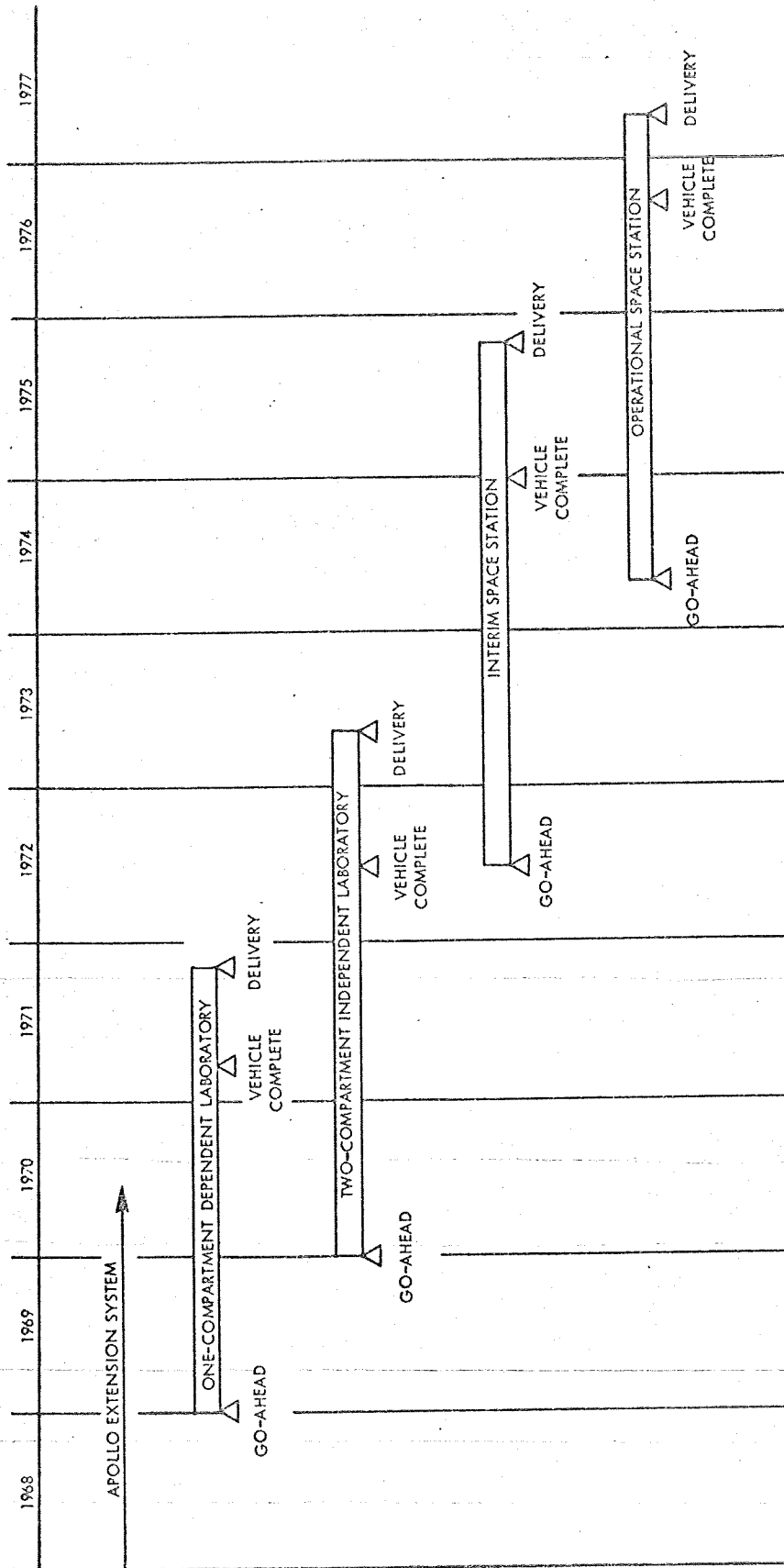


FIG. 6-1 SUMMARY DEVELOPMENT SCHEDULE FOR THE MODULAR MULTIPURPOSE SPACE STATION

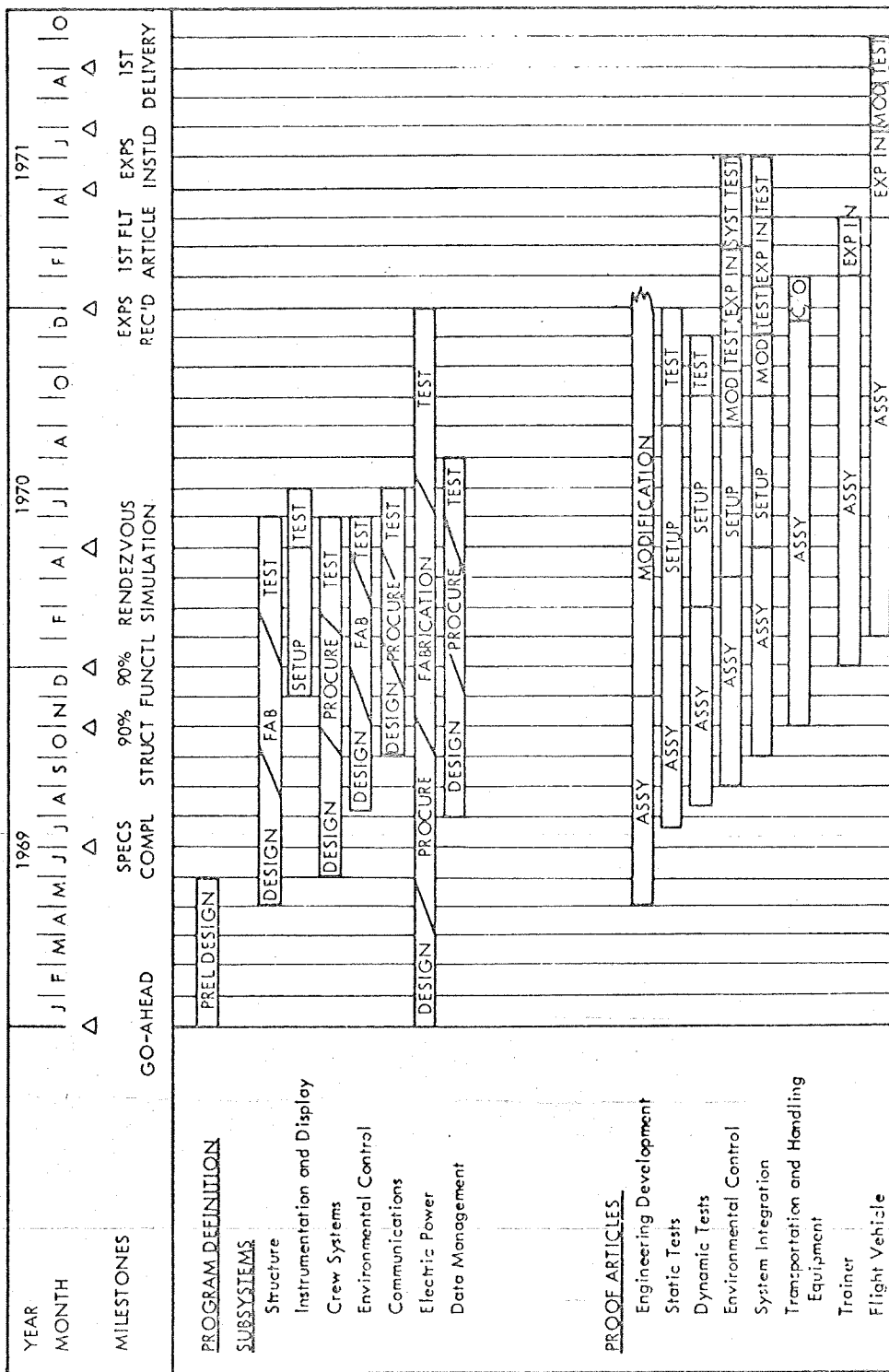


FIG. 6-2 ONE-COMPARTMENT DEPENDENT LABORATORY DEVELOPMENT SCHEDULE

6.1.1.3 Instrumentation and Display Subsystem

The basic Apollo instrumentation and displays will be adequate for all flight operations; however, an instrumentation and display subsystem must be provided for experiments, compartment environmental conditions, extra-vehicular activities and docking, latch-up, and sealing.

6.1.1.4 Data Management Subsystem

The Apollo command module data management provisions will be utilized essentially without modification. Additional data storage provisions are dictated by the experimental flight role and the limited communication time.

6.1.1.5 Communications, Command and Tracking Subsystem

The command module provides all major communication equipment. There is, however, some minor effort required to provide the intercom between the laboratory and the command module and the remote control of flight equipment in the command module.

6.1.1.6, Navigation and Guidance Subsystem

The Apollo command and service module navigation and guidance provisions are generally adequate for the One-Compartment Dependent Laboratory program. Minor modification and repackaging will be required to permit on-board maintenance and repair, and a horizon sensor must be added for continuous attitude reference for conserving crew operating time.

6.1.1.7 Stabilization and Control Subsystem

The performance of the stabilization and control subsystem in the Apollo command and service modules is adequate for the One-Compartment Dependent Laboratory. Some repackaging will be required to facilitate equipment repair and maintenance on the 45-day missions.

6.1.1.8 Electric Power Subsystem

The Apollo service module provides a portion of the electric power for the One-Compartment Dependent Laboratory with the remainder being supplied by

Apollo fuel cells mounted on the module. Early action is required to ensure that fuel cells are available in time for the system test. Approximately 12 months are required for delivery of a fuel cell after its specification is released and procurement is initiated.

6.1.1.9 Propulsion Subsystem

The propulsion subsystem in the Apollo service module is adequate for orbit injection and attitude control of the One-Compartment Laboratory. Additional propellant and pressurant gas tankage will be necessary and a thorough reliability analysis substantiated by test data will be needed to establish redundancy, spares, and maintainability requirements.

6.1.1.10 Crew Subsystems

Basic living quarters are provided by the command module but some modification will be required to ensure that all equipment is sized to accommodate three men for a maximum period of 45 days without resupply.

6.1.1.11 Proof Articles

Proof articles are provided for engineering development, static test, dynamic test, complete Environmental Control Subsystem checkout, subsystem integration, transportation and handling equipment tests, and training. A series of wooden mockups will be utilized for subsystem integration and system development.

One complete wooden mock-up of the interior and exterior of the laboratory will be used as an engineering development tool. This mockup will contain crew stations, work and rest areas, displays and controls, airlocks, windows, and experimental and support equipment. It will also be used to demonstrate installation and maintenance capability.

A second wooden mockup of the interior of the laboratory will be used to develop the man-system interface involving such areas as work station layout, locomotion devices, panel design and lighting. A full scale wooden mockup will also be provided with metal hardpoints for docking

procedure demonstration. Included will be the Apollo nose structure, docking ports, and mechanism latches. In addition, fluid and electrical umbilical connections will be provided for Apollo laboratory compatibility demonstrations.

6.1.2 Two-Compartment Independent Laboratory

The Two-Compartment Independent Laboratory development schedule, Fig. 6-3, requires prompt action in many areas upon receipt of contract go-ahead, in order to provide the independent subsystem operation required of the laboratory for a three- to six-man crew over a 45-day to one-year mission duration. For example, assuming contract go ahead in January 1970, and prompt initiation of the Environment Control and Life Support Subsystem development, it is expected that the component development can be accomplished by October 1971. The proof test of the complete subsystem will be conducted on a flight module laboratory in a vacuum chamber with actual or simulated thermal, atmosphere, contaminant, and metabolic loads. This test will be accomplished in October 1972 and this will permit equipment installation in the first flight vehicle for delivery in April 1973.

6.1.2.1 Structure

As a result of the intensive broad scale structural design effort on the One-Compartment Laboratory module, only relatively minor tasks remain on the Independent Laboratory. Joining provisions for the two modules and structural accommodations for new environmental control line and duct routing are examples of work to be done on this laboratory.

6.1.2.2 Environmental Control and Life Support Subsystem

The environmental control and life support subsystem must be augmented by water recovery from urine, a regenerable carbon dioxide removal system, and two-gas atmosphere control and storage equipment.

6.1.2.3 Instrumentation and Display Subsystem

The instrumentation and display subsystem will require some amplification for independent operation of the Two-Compartment Laboratory and

FIG. 6-3 TWO-COMPARTMENT INDEPENDENT LABORATORY DEVELOPMENT SCHEDULE

for experiments. For example, electrical power generation and consumption, orbit altitude maintenance and environmental status such as gas consumption and generation, temperature and humidity must all be readily monitored for any necessary correction.

6.1.2.4 Data Management Subsystem

The Data Management Subsystem is an application of Apollo hardware with increased data storage and handling capacity, obtained by utilization of two Apollo data management systems.

6.1.2.5 Communication, Command, and Tracking Subsystem

The Communications, Command, and Tracking Subsystem will be primarily an application of an additional set of the Apollo subsystem.

6.1.2.6 Navigation and Guidance Subsystem

The Navigation and Guidance Subsystem requires development effort to produce a long-life inertial platform and long-life integrating gyros. The long-life microminiature computer and star tracker are new but available elements in this system. This subsystem development is undertaken at this time to ensure the required reliability for the Interim Space Station configuration.

6.1.2.7 Stabilization and Control Subsystem

In the Stability and Control Subsystem, a gas-bearing differential gyro, a control moment gyro, and associated electronics must be integrated to provide the required reliability and accuracy for this mission and the longer duration missions to be accomplished with the next spacecraft generation.

6.1.2.8 Electric Power Subsystem

The electric power supply is primarily provided by solar arrays and a basic 5-kw solar photovoltaic power module must be developed. Major problems are the production of an adequate quantity of solar cells and the development of light-weight, long-life batteries such as the recommended silver-cadmium cells.

6.1.2.9 Propulsion Subsystem

The propulsion subsystem available in the Apollo service module is sufficient for the orbit injection and attitude control required by the Two Compartment Independent Laboratory. Some augmentation of the propellant and pressurant gas storage equipment will be required for the longer duration missions.

6.1.2.10 Crew Subsystems

The Apollo crew subsystem designs will be utilized but will be sized to accommodate six men without depending on any of the command module facilities. Radiation shielding will also be provided because of solar flare possibilities during the one-year mission.

6.1.3 Interim Modular Multipurpose Space Station

The Interim Space Station development schedule, Fig. 6-4, requires prompt parallel development effort in several areas upon receipt of contract go-ahead to avoid unnecessary flight delay. For example, rapid data transmission is essential to this laboratory for two reasons. First, with the much larger laboratory and staff, many more experiments with correspondingly increased data will be completed per unit of time. Second, after the initial launch and satisfactory operation is established, it can be expected that only stations in the North American continent will be used to receive data from the laboratory for the balance of the five year mission. This condition will reduce the opportunities to transmit data from seven transmissions to three per orbit. Assuming a contract go-ahead of June 1972, the communications development effort is expected to result in proven rapid data transmission by August 1974. System integration will be complete March 1975 in time for installation in the flight vehicle for first delivery June 1975.

6.1.3.1 Structure

As was the case with the Two-Compartment Independent Module, the intensive broad scale structural design effort expended on the One-Compartment Module has minimized the structural task on this vehicle.

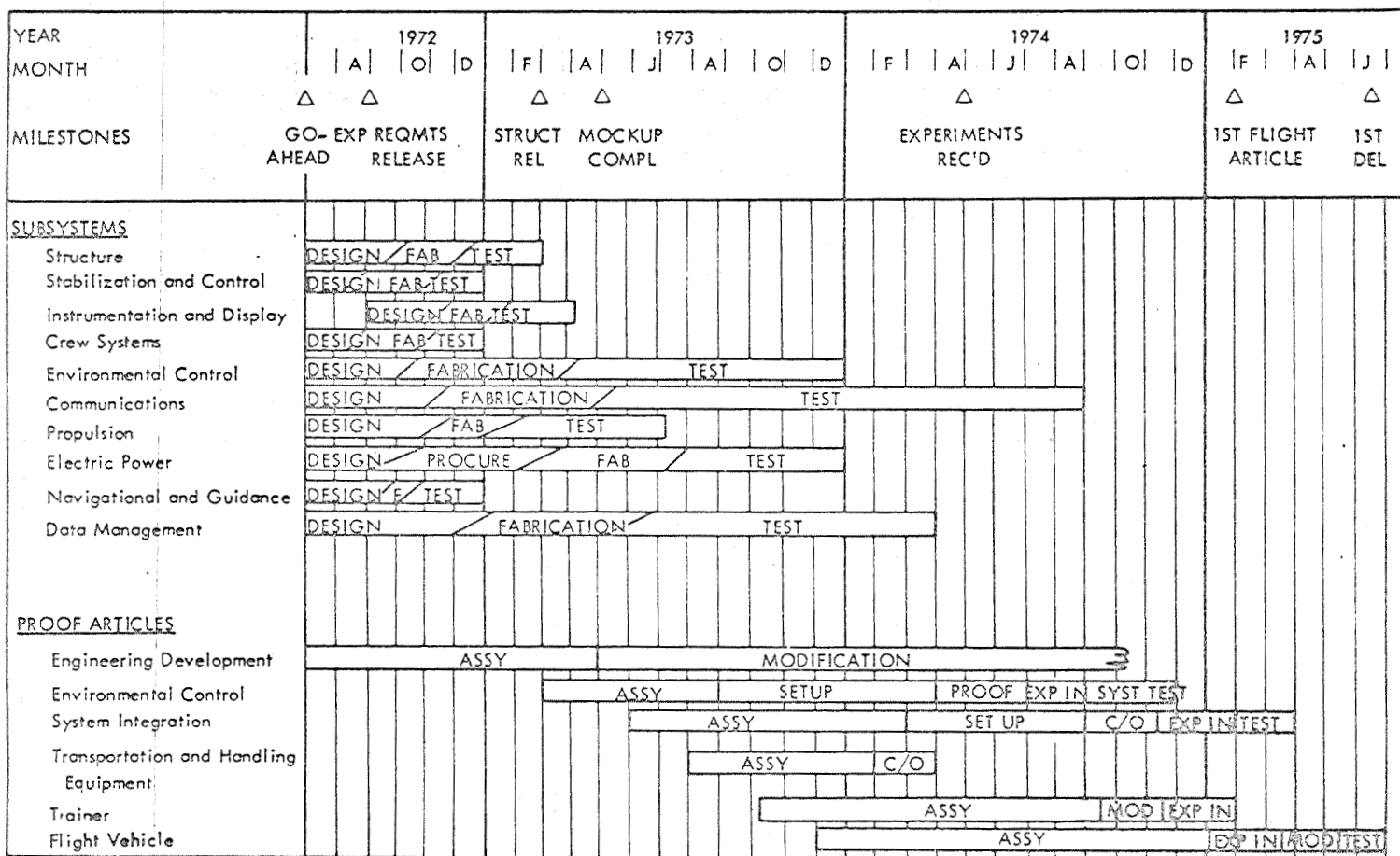


FIG. 6-4 INTERIM MODULAR MULTIPURPOSE SPACE STATION DEVELOPMENT SCHEDULE

Attachment provisions, separable adapter skirt to the Saturn IVB stage and separation provisions for the propulsion system, after orbit circularization, are representative structural tasks to be accomplished.

6.1.3.2 Environmental Control and Life Support Subsystem

The Environmental Control and Life Support Subsystem is supplemented by oxygen regeneration equipment.

6.1.3.3 Instrumentation and Display Subsystem

Instrumentation and Display Subsystem changes involve the addition of modular display and control units and a new control compartment to accommodate the expanded operations and functions of the larger laboratory.

6.1.3.4 Data Management Subsystem

The Data Management Subsystem is amplified by on-board data processing capability, increased data handling capability, increased data handling rates, and a reduced ratio of data input to data transmitted.

6.1.3.5 Communication, Command and Tracking Subsystem

The Communications Subsystem includes a complete intra-laboratory audio and visual system in addition to the development of a new rapid data transmission capability for the laboratory. Parallel development is required on the ground equipment to accomplish error-free reception of this rapid data transmission. Multiple antenna phase control equipment would be incorporated in this station to flight-rate the equipment for later use on the large rotating space station where its use is essential.

6.1.3.6 Navigation and Guidance Development

The Navigation and Guidance Subsystem is modified by the replacement of the Apollo integrating accelerometer with a new long life integrating accelerometer which requires some development at this time.

6.1.3.7 Stabilization and Control Subsystem

The Stabilization and Control Subsystem requires the redesign of its microelectronics and the installation of a large control-moment gyro in

order to attain the attitude holding accuracy that is necessary for satisfactory experimentation during this five-year mission. The large gyro has the additional advantage of appreciable reaction control fuel savings by maintaining attitude control in spite of the many internal and external deviating forces such as crew movement, equipment operation and repositioning, gravity gradient forces, and aerodynamic moments.

6.1.3.8 Electric Power Subsystem

The Electric Power Subsystem is an extension of the 5-kw module previously developed for the Two-Compartment Independent Laboratory. Two power modules are required.

6.1.3.9 Propulsion Subsystem

A new orbit injection Propulsion Subsystem is required for this station configuration. The development of 200-pound thrust engines at this time will ensure fully flight-rated attitude control engines for the rotating mode of the Operational Modular Space Station. Similarly, the development of the new 65-pound thrust attitude control engines for this Interim Station will provide attitude control engines for the non-rotating mode of the Operational Station.

6.1.3.10 Crew Subsystems

Crew systems in general require some expansion to provide for the nine man crew. Radiation shielding is increased because of the possibility of greater exposure as a result of the longer flight period and a larger crew.

6.1.4 Operational Modular Multipurpose Space Station

The Operational Space Station development schedule, Fig. 6-5, again indicates the necessity for prompt parallel development in several areas upon receipt of contract go-ahead in order to provide the earliest practicable availability of this laboratory. The space station will accommodate up to a 36-man crew on a 5- to 10-year mission when resupplied on a 3-month cycle.

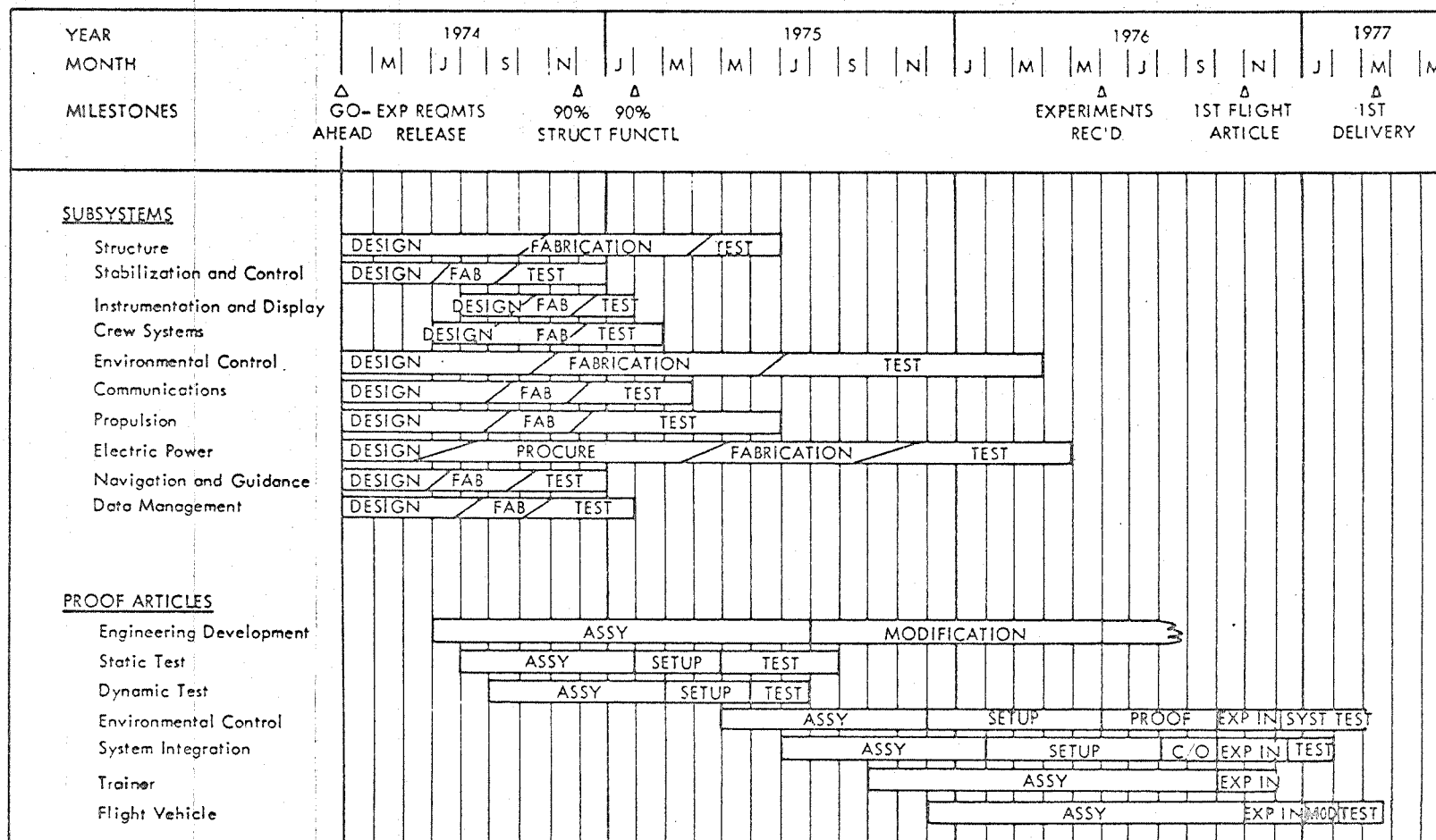


FIG. 6-5 OPERATIONAL MODULAR MULTIPURPOSE SPACE STATION DEVELOPMENT SCHEDULE

6.1.4.1 Structure

Although the modular construction is utilized in the radial modules and the universal docking ports readily accommodate the new access tubes, the addition of the hub and the external load-carrying shroud will require additional structural development since they are both new designs.

6.1.4.2 Environmental Control and Life Support Subsystem

The Environmental Control and Life Support Subsystem is supplemented by fecal water reclamation for oxygen makeup. Four of the subsystems developed for the Interim Station are used in this spacecraft, i.e., one subsystem for each radial module and one in the hub. Provisions are made for the hub hangar pump-down prior to logistic spacecraft acceptance or release in order to conserve the atmosphere supply.

6.1.4.3 Instrumentation and Display

Instrumentation and display areas are materially increased in order to provide the necessary intelligence for control of the space station and to monitor flight and environment conditions for the much larger number of experiments in process. The subsystem is composed of the same modular units used in the Interim Space Station. In addition to the primary control compartment, there will be a backup control compartment using, for the most part, equipment identical to the primary control compartment.

6.1.4.4 Data Management Subsystem

The principal development effort in the Data Management Subsystem involves data compression, time-sharing subunits and increased data handling capability. The three Interim Station Data Management Subsystems, one in each radial arm of the station, are supplemented by a switching apparatus for time sharing capability.

6.1.4.5 Communication, Command and Tracking Subsystem

The Communications Subsystem requires the addition of a phase control for the antenna output. This phase control is accomplished by the incorporation of feed-back control applied to each antenna transmitting system.

Development of this feature will have been accomplished on the Interim Station. A complete audio-visual closed circuit TV, also developed for the Interim Station, is provided throughout the laboratory hub and radial arms.

6.1.4.6 Navigation and Guidance Subsystem

The Navigation and Guidance Subsystem is basically the same as that used on the Interim Station except for the replacement of the micromin computer by a centralized computer. Some modifications are required in the system to accommodate the rotation of the space station.

6.1.4.7 Stabilization and Control Subsystem

The Stabilization and Control Subsystem developed for the Interim Station is largely applicable to this much larger spacecraft. It will be supplemented by a water balance system to achieve dynamic and static balance control. The control moment gyro is redesigned for this application, and the attitude control electronics are redesigned to accommodate both zero-g and rotating conditions. The spin and de-spin system is added, and the sun sensors are added for full time rotational solar orientation.

6.1.4.8 Electric Power Subsystem

The Electric Power Subsystem consists of solar arrays and rechargeable batteries supplemented by the Apollo fuel cell power modules required for station start-up. The six five-kilowatt solar power modules used on this station are identical with those used on the Interim Station. No new development is required other than the integration of the six five-kilowatt modules and fuel cells into a 30-kw system. The major delay in this program is the production and actual fabrication of the number of solar cells required for the six 1360-square foot arrays to be employed on this station.

6.1.4.9 Propulsion Subsystem

The Propulsion Subsystem uses the LEM descent engine for orbit injection. The Interim Space Station attitude control engines are mounted on the

Operational Station hub for zero-g attitude control. The Interim Station orbit injection engines are repackaged in clusters and mounted on the outer end of the radial modules to provide rotating attitude control propulsion. Unless experiment requirements impose more severe requirements on the propulsion subsystem, the only development necessary will be the application of these developed propulsion units to the Operational Space Station.

6.1.4.10 Crew Subsystems

The crew subsystems are materially increased in capacity to accommodate 36 men. The capacity is increased by the use of three of the modular crew compartment installations from the Interim Space Station and one of the modular compartments modified to fit into the zero-gravity section of the central hub.

6.2 COST ANALYSIS

This section presents the methods and results obtained from the development of program costs for the Modular Space Station concept. This is accomplished by indicating the data sources, defining the subsystems, and describing the costs of DT & E, manufacturing, operation, and program management. A cost analysis summary is presented in paragraph 6.2.6, along with the costs of an alternate design approach. A section on underestimating factors is included to indicate the magnitude of some of the cost estimating errors that have occurred in past programs. The costs are presented for planning purposes only and do not reflect or imply direct quotes on the part of the contractor or any of the subcontractors.

The space systems analyzed for cost purposes are the One-Compartment Dependent Laboratory, the Two-Compartment Independent Laboratory, the Interim Space Station, and the Operational Space Station.

The basic assumptions for these systems are:

- The development and operation of the various space stations is a continuous effort and each succeeding space station is dependent upon the development and operation of the preceding one.
- There is only one operational station for each configuration.
- There are no vehicles allocated for unmanned flight test.
- All costs are in current 1965 dollars.
- Costs are only those associated with the space stations and do not include logistic spacecraft or their associated costs. The exceptions are those stations launched with the Apollo command and service modules, which necessarily include the Apollo as the logistic vehicle.

6.2.1 Cost Data Sources

The sources of cost information for this study are: vendors and possible subcontractors, published historical costs, NASA data, in-house experience data, and other related sources. The data from vendors and possible subcontractors were obtained by personal visits. The information received has been used with utmost discretion and is presented with no reference to source because of requests by the vendors to treat it in this manner.

The cost information received was expanded to reflect the total system approach rather than isolated parts. In other words, the subsystems costs also include the prime contractor contribution to the subsystem level development and the related costs, such as total system tests and documentation.

6.2.2 Subsystem Definition

Definitions of the subsystems used for costing purposes are listed below:

- Structure and mechanical - all items associated with the space-frame and the installation of on-board systems.
- Navigation and guidance - the inertial platform, sensors, and computer.

- Attitude control (including stabilization - sensors, rate gyros, mechanical devices (actuators), inertia wheels, static balance devices, and thrusters.
- Crew systems - devices which provide for the comfort and safety of the crew, excluding expendable food and supplies.
- Environmental control - the atmosphere, water, waste management and thermal control systems.
- Data management - all the equipment necessary to receive, process, and store data.
- Displays - visual aids necessary to convey information to the crew and controls such as knobs, toggle switches, etc.
- Communications - all radio, antenna, and amplifying equipment.
- Electrical power - the primary electrical generating equipment (solar cells, etc.) and secondary power generating equipment (batteries); also the distribution and conditioning equipment.
- Propulsion - all engines, plumbing, valves, and tankage except that portion included in attitude control.

Normally, the laboratory experimental equipment would be included as a subsystem, but for this study it is not because the final mission task model has not yet been defined. When the mission task model is selected, realistic costs can be included.

6.2.3 DT & E and Manufacturing Costs

The functional cost categories at the subsystem level are:

- DT & E - includes all the labor and materials required to develop the subsystem up to the operational level. This element is subdivided into design and development, tests, and test hardware.
- Fabrication - includes all the labor and materials required for producing the operational station.

The cost units which are end item oriented but more functional in nature are:

- Design studies and system analysis - this category is analogous to system engineering and includes costs of vehicle oriented engineering and studies performed by contractors.
- Integrated systems test - includes the test labor cost at the vehicle level.

- Tooling - includes the costs of jigs and fixtures necessary to support the hardware manufacture at the vehicle level.
- GSE - includes the costs of the ground support equipment necessary for the test and operation of the vehicle equipment, but excludes special test equipment which is included at the subsystem level.

The cost units which are treated as direct functions of the vehicles are:

- Quality Control - this item is included at the subsystem level but is included as a non-add item at the end item level for analysis purposes.
- Spares - included as a direct function of the manufacturing effort. This category includes all the spare parts and equipment required to support the space station.

A cost breakdown of each of the stations, by subsystem and functional cost category for DT & E and fabrication, are shown in Tables 6-1 through 6-4.

6.2.4 Operational Costs

The operational costs include all the costs that are necessary to launch, operate, and maintain the system over a specified period of time, excluding the space vehicle manufacturing costs. The time periods for this study are:

One-Compartment Dependent Laboratory	= 45 days
Two-Compartment Independent Laboratory	= 1 year
Interim Space Station	= 5 years
Operational Space Station	= 10 years

6.2.4.1 Apollo and Adapter Costs

The Apollo and adapter includes the command and service modules with the adapter. The cost of these items was derived from published historical data. A percent factor is included for prime contractor contribution to the modification and adaptation to the space station application. The Apollo costs are associated with the One-Compartment and Two-Compartment Laboratories. The total Apollo cost for each program is \$25.4 million.



TABLE 6-1
ONE-COMPARTMENT DEPENDENT LABORATORY - COST BREAKDOWN
(Millions of Dollars)

	<u>Tests</u>	<u>Design and Development</u>	<u>Test Hardware</u>	<u>Total DT&E</u>	<u>Fabrication</u>	<u>Total</u>
SUBSYSTEM LEVEL						
Structure & Mech. Systems	2.70	24.25	25.92	52.87	4.32	57.19
Navigation & Guidance	4.98	4.97	16.80	26.75	4.95	31.70
Attitude Control	*	*	*	*	*	*
Crew Systems	0.60	5.45	0.70	6.75	0.14	6.89
Environmental Control	1.14	12.25	2.34	15.73	0.39	16.12
Displays	2.00	3.00	1.46	6.46	0.24	6.70
Communications	0.80	5.15	0.35	6.30	0.07	6.37
Electrical Power	*	*	*	*	*	*
Propulsion	*	*	*	*	*	*
Data Management	<u>0.25</u>	<u>2.27</u>	<u>0.08</u>	<u>2.60</u>	<u>0.02</u>	<u>2.62</u>
Total Subsystem	12.47	57.34	47.65	117.46	10.13	127.59
SPACE STATION LEVEL						
Design Studies & System Analysis		12.90		12.90		12.90
Integrated Systems Test		13.80		13.80		13.80
Tooling		(2.00)		(2.00)		(2.00)
GSE		46.00		46.00		46.00
APOLLO and ADAPTER					25.40	25.40
QUALITY CONTROL					(3.38)	(3.38)
SPARES					<u>1.22</u>	<u>1.22</u>
Station Subtotal	12.47	130.04	47.65	190.16	36.75	226.91

*Included in the Apollo

TABLE 6-2
TWO-COMPARTMENT INDEPENDENT LABORATORY - COST BREAKDOWN
(Millions of Dollars)

SUBSYSTEM LEVEL	Tests	Design and Development	Test Hardware	Total DT&E	Fabrication	Total
Structure & Mech. Systems	3.24	29.21	17.75	50.20	9.32	59.52
Navigation & Guidance	20.00	15.15	20.40	55.55	3.30	58.85
Attitude Control	6.90	62.40	19.70	89.00	2.20	91.20
Crew Systems	1.80	16.20	1.04	19.04	0.21	19.25
Environmental Control	22.48	89.62	15.22	127.32	2.03	129.35
Displays	1.50	13.50	1.55	16.55	0.26	16.81
Communications	0.80	5.15	2.24	8.19	0.07	8.26
Electrical Power	2.93	6.97	31.38	41.28	5.23	46.51
Propulsion	*	*	*	*	*	*
Data Management	1.48	13.32	2.02	16.82	0.51	17.33
Total Subsystem	61.13	251.52	111.30	423.95	23.13	447.08
SPACE STATION LEVEL						
Design Studies & System Analysis		13.40		13.40		13.40
Integrated Systems Test		35.40		35.40		35.40
Tooling		(2.58)		(2.58)		(2.58)
GSE		120.00		120.00		120.00
APOLLO and ADAPTER					25.40	25.40
QUALITY CONTROL					(10.22)	(10.22)
SPARES					2.88	2.88
Station Subtotal	61.13	420.32	111.30	592.75	51.41	644.16

*Included in the Apollo

TABLE 6-3
INTERIM SPACE STATION - COST BREAKDOWN
(Millions of Dollars)

SUBSYSTEM LEVEL	Tests	Design and Development	Test Hardware	Total DT&E	Fabrication		Total
Structure & Mech. Systems	4.95	44.55	55.90	105.40	22.44		127.84
Navigation & Guidance	10.00	4.06	4.95	19.01	2.82		21.83
Attitude Control	0.69	6.24	19.70	26.63	2.20		28.83
Crew Systems	0.90	8.10	0.74	9.74	0.31		10.05
Environmental Control	22.48	11.24	11.60	45.32	1.85		47.17
Displays	4.00	6.00	2.48	12.48	0.39		12.87
Communications	17.80	8.40	14.05	40.25	4.98		45.23
Electrical Power	2.93	2.00	29.07	34.00	9.69		43.69
Propulsion	0.16	1.46	4.72	6.34	0.66		7.02
Data Management	2.00	3.00	4.98	9.98	0.44		10.42
Total Subsystem	65.91	95.05	148.19	309.15	45.80		354.95
SPACE STATION LEVEL							
Design Studies & System Analysis		19.70		19.70			19.70
Integrated System Test		47.50		47.50			47.50
Tooling		(5.11)		(5.11)			(5.11)
GSE		90.00		90.00			90.00
QUALITY CONTROL					(8.73)		(8.73)
SPARES					5.50		5.50
Station Subtotal	65.91	252.25	148.19	466.35	51.30		517.65



TABLE 6-4
OPERATIONAL MODULAR MULTIPURPOSE SPACE STATION - COST BREAKDOWN
(Millions of Dollars)

	<u>Tests</u>	<u>Design and Development</u>	<u>Test Hardware</u>	<u>Total DT&E</u>	<u>Fabrication</u>	<u>Total</u>
SUBSYSTEM LEVEL						
Structure & Mech. Systems	9.35	84.15	123.50	217.00	76.32	293.32
Navigation & Guidance	7.00	3.54	3.30	13.84	3.09	16.93
Attitude Control	2.77	24.95	17.80	45.52	3.57	49.09
Crew Systems	1.20	10.80	1.71	13.71	1.34	15.05
Environmental Control	33.72	16.86	16.30	66.88	6.80	73.68
Displays	2.00	3.00	3.01	8.01	1.03	9.04
Communications	15.70	1.68	11.20	28.58	7.48	36.06
Electrical Power	2.93	2.00	48.78	53.71	24.39	78.10
Propulsion	0.14	1.31	2.85	4.30	3.03	7.33
Data Management	<u>2.00</u>	<u>3.00</u>	<u>4.24</u>	<u>9.24</u>	<u>0.44</u>	<u>9.68</u>
Total Subsystem	76.81	151.29	232.69	460.79	127.49	588.28
SPACE STATION LEVEL						
Design Studies & System Analysis		51.00		51.00		51.00
Integrated Systems Test		75.00		75.00		75.00
Tooling		(8.22)		(8.22)		(8.22)
GSE		92.00		92.00		92.00
QUALITY CONTROL					(11.34)	(11.34)
SPARES					<u>15.30</u>	<u>15.30</u>
Station Subtotal	76.81	369.29	232.69	678.79	142.79	821.58

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6.2.4.2 Facilities

The facility costs included in this report are those costs stemming from manufacturing, testing, assembly, and launch pad modification.

For generation of the cost for new manufacturing facilities, the following relationship applies:

$$\begin{aligned} \text{CT} &= \text{Total Manufacturing Facilities} = \text{SQF} \times \text{PFCF} \times \text{CCI} \\ \text{SQF} &= \text{Total number of square feet required} = 245,000 \\ \text{PFCF} &= \text{Cost Factor} = 43.2 \text{ (average)} \\ \text{CCI} &= \text{Cost Construction Index} = 1 \\ \text{CT} &= 245,000 \times 43.2 \times 1 = \$10.6 \text{ million} \end{aligned}$$

Test facility costs include environmental testing, static firing, solar simulator, and miscellaneous testing. Also included as test facility costs are the costs for assembly, disassembly and checkout of the space station unit being tested.

It is assumed that the facilities at Complex 39 will be operable and available for use on this project. Modifications to the arming and umbilical tower are included. If operational schedules do not permit the use of the Vertical Assembly Building, a new facility will be required for assembling and mating the space station to the launch vehicle and for other associated functions.

These new facility costs for the Kennedy Space Center, which are estimated at \$15.0 million, excluding land value and site development, are not included in the cost of this program.

It is assumed that the environmental test facility at the Manned Spacecraft Center will be available for testing purposes. Assembly and training facilities costs at MSC are not included since the requirements are not defined at this time. It can be assumed safely that the new facilities will be similar to those required at the Kennedy Space Center, in the cost range of \$10.0 million to \$15.0 million.

Down-range facilities, the GOSS network, and test and checkout facilities at the Kennedy Space Center are assumed to be available.

All facility costs are included in the Interim Space Station costs except for the solar simulator facilities required for the testing of the solar panels for the Two-Compartment configuration. (See Table 6-5.)

TABLE 6-5 FACILITIES COSTS
(Millions of Dollars)

<u>Facilities</u>	<u>One-Compartment Laboratory</u>	<u>Two-Compartment Laboratory</u>	<u>Interim Space Station</u>	<u>Operational Space Station</u>
Manufacturing			10.60	
Test		10.00	13.80	
Assembly			2.00	
Launch Pad Modification			3.00	
Maintenance			7.10	
Total Facilities	0	10.00	36.50	0

6.2.4.3 Launch Vehicles

The launch vehicle for the one-, two-, and six-compartment stations in low earth orbits is the Saturn IB configuration. The launch vehicle proposed for the Operational Space Station is the two-stage, earth orbit configuration of the Saturn V. The latter configuration consists of the S-IC and S-II stages with a repackaged instrumentation unit. The sources of all costs associated with the launch vehicles are current NASA documents. The cost of the Saturn IB is \$34 million and the cost of the Saturn V is \$100 million. These costs include launch services.

6.2.4.4 Operations

- Astronaut training
- Pay and allowances
- Space station maintenance
- Miscellaneous

The Miscellaneous category includes propellants, stocks, and space station transportation.

The costs for the above categories, with the exception of astronaut training, are generated with gross estimating procedures. Astronaut training costs are estimated by assuming a nominal training program and a minimum number of trained astronauts. The assumptions for the nominal program are:

- One year maximum time in orbit per man
- Twenty-five percent of the total required personnel are trained as astronauts with a cost factor of 100 percent. These costs are attributed to the logistic system and not to the space station.
- Twenty-five percent of the total required personnel are trained as engineers and assistant astronauts with a cost factor of 25 percent, attributable to the space station.
- Fifty percent of the total required personnel are trained as engineers and scientists with training on engineering equipment and specialized equipment maintenance with a cost factor of 10 percent, attributable to the space station.
- Two years intensive training period. The trainees enter the force at a uniform rate over the total modular program life.

With the above assumptions the following procedure has been developed:

	<u>One Compt</u>	<u>Two Compt</u>	<u>Interim Station</u>	<u>Operational Station</u>
A. Crew Size	3	6	9	24
B. Years of Operation	1/8	1	5	10
C. Subtotal (A x B)	3	6	45	240
D. 25% Backup (0.25 x C)	1	2	11	60
E. Total to be trained (C + D)	4	8	56	300
F. Logistics System (0.25 x E)	1	2	14	75
G. Engineers & Asst. Astronauts (0.25 x E)	1	2	14	75
H. Engineers & Scientists (0.50 x E)	2	4	28	150

The total cost per man, by classification, associated with the space station is represented by: (cost factor for training per year) x (percentage factor) x (number of years required per man).

- Engineers and assistant astronauts
 $(\$1.0 \times 10^6) \times (0.25) \times (2) = \$0.5 \text{ million per man}$
- Engineers and scientists
 $(\$1.0 \times 10^6) \times (0.10) \times (2) = \$0.2 \text{ million per man}$

The total astronaut training costs are shown in Table 6-6 along with the remaining operations costs.

TABLE 6-6
OPERATIONS COST SUMMARY
(Millions of Dollars)

	<u>One Compt</u>	<u>Two Compt</u>	<u>Interim Station</u>	<u>Operational Station</u>
Astronaut Training	0.90	1.80	12.60	67.50
Pay and Allowances	0.90	3.40	16.80	33.00
Space Station Maintenance	0.22	2.60	25.65	127.49
Miscellaneous	<u>0.80</u>	<u>1.60</u>	<u>3.40</u>	<u>6.70</u>
OPS Total	2.82	9.40	58.45	234.69

6.2.5 Program Management

The program management cost category includes only the overall program level; costs for program supervision at the subsystem level are included in the individual subsystem costs. This method has the advantage of indicating areas of cost sensitivity at a lower level and does not misrepresent any of the total subsystem costs. It also gives a more accurate picture of the functional cost categories, such as program management, by not having a high aggregate cost with little meaning.

The NASA program management cost category should be treated in the same manner as the above. Costs have not been included for this cost category because much of the cost impact is a direct function of the NASA policy and the related decision making.

The costs (in millions of dollars) for the program management element are:

One-Compartment	15.80
Two-Compartment	43.27
Interim Station	36.40
Operational Station	63.50

6.2.6 Cost Analysis Summary

The modular approach is a continuous effort and none of the space stations should be taken out of context. A complete revision of the cost analysis is necessary if one of the individual stations is selected as a final objective, since each of the stations is dependent upon the development of the previous one. The total program cost (summarized in Table 6-7) based on the modular approach is \$2.923 billion. The funding schedule that is associated with the space stations is shown in Figure 6-6.

6.2.7 Station Cost Comparisons

The modular program costed above consists of a sequential development from the One-Compartment Dependent Laboratory to the Operational Multipurpose Space Station, with maximum advantage being taken of prior developments at each point in the program. An alternative approach would be to develop each of the programs independently without taking advantage of the growth capability which is inherent in the modular approach.

In order to present costs for an alternative approach for comparative purposes, the costs in Table 6-8 were generated. The MORL-type station is comparable to the Interim Modular station and the LORL-type station is comparable to the Operational Modular space station. For the comparison, it was assumed that the One- and Two-Compartment Laboratories would not have different costs, but the Interim and Operational stations would be incremental. Total program costs are shown in Table 6-9 for

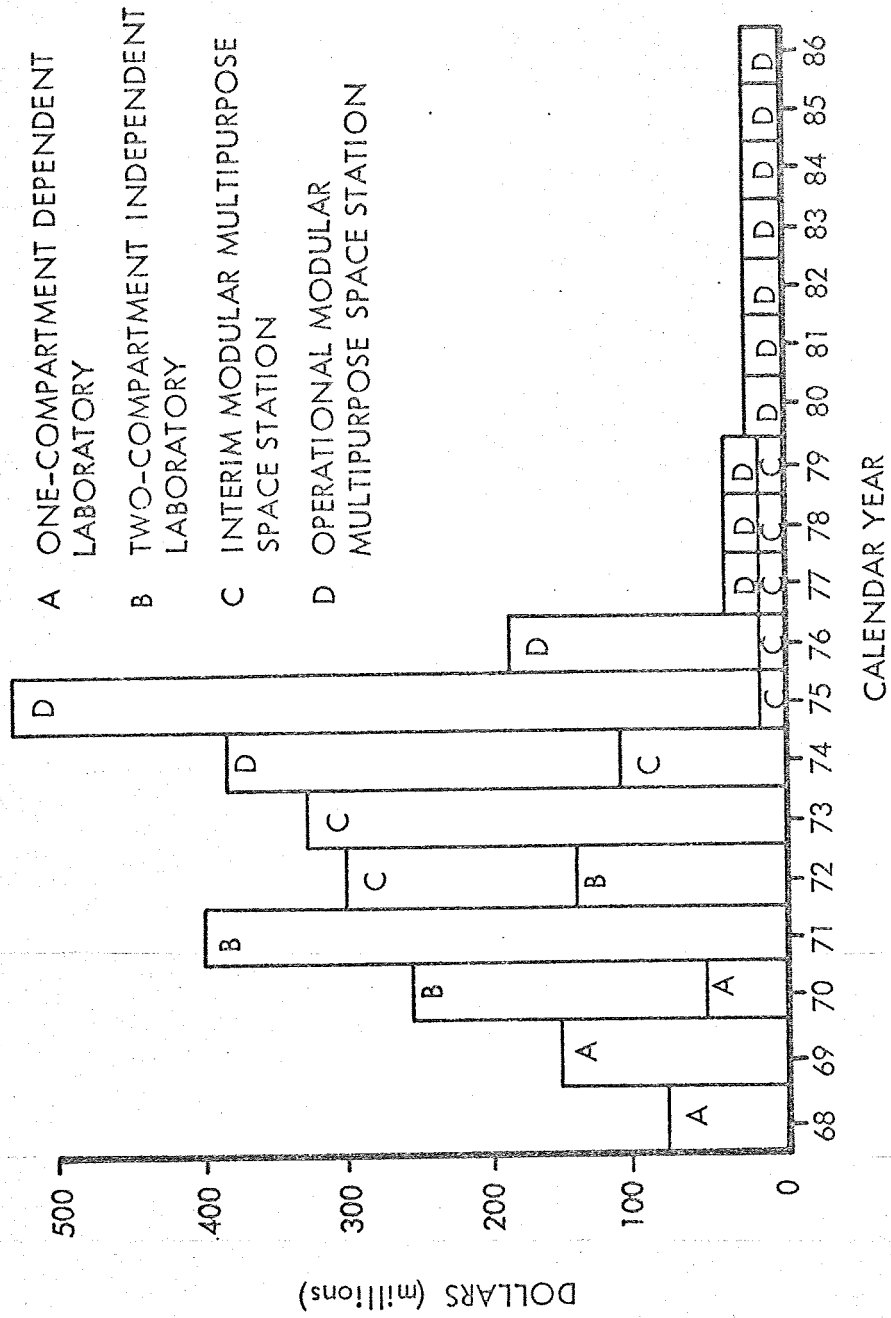


FIG. 6-6 PROJECTED FISCAL FUNDING



TABLE 6-7

MODULAR MULTIPURPOSE SPACE STATION COST SUMMARY

(Millions of Dollars)

	<u>One-Com- partment</u>	<u>Two-Com- partment</u>	<u>Interim Station</u>	<u>Operational Station</u>
DT&E				
Subsystem Level				
Design & Development	57.34	251.52	95.05	151.29
Tests	12.47	61.13	65.91	76.81
Test Hardware	47.65	111.30	148.19	232.69
Space Station Level				
Design Studies & System Analysis	12.90	13.40	19.70	51.00
Integrated Systems Test	13.80	35.40	47.50	75.00
Tooling	(2.00)	(2.58)	(5.11)	(8.22)
GSE	46.00	120.00	90.00	92.00
Total DT&E	<u>190.16</u>	<u>592.75</u>	<u>466.35</u>	<u>678.79</u>
MANUFACTURING				
Fabrication	10.13	23.13	45.80	127.49
Quality Control	(3.38)	(10.22)	(8.73)	(11.34)
Spares	1.22	2.88	5.50	15.30
Total MANUFACTURING	<u>11.35</u>	<u>26.01</u>	<u>51.30</u>	<u>142.79</u>
OPERATIONAL				
APOLLO and ADAPTER	25.40	25.40	0	0
Facilities	--	10.00	36.50	--
Launch Vehicle & Launch Services	34.00	34.00	34.00	100.00
Operations	2.82	9.40	58.45	234.69
Total OPERATIONAL	<u>62.22</u>	<u>78.80</u>	<u>128.95</u>	<u>334.69</u>
PROGRAM MANAGEMENT				
NASA	*	*	*	*
Contractor	15.80	43.27	36.40	63.50
Total Program Cost	<u>279.53</u>	<u>740.83</u>	<u>683.00</u>	<u>1,219.77</u>

*To be determined by the NASA
Numbers in parentheses are non-add items.

TABLE 6-8
MEDIUM AND LARGE SPACE STATION COST BREAKDOWN
(Millions of Dollars)

	MORL-TYPE STATION				LORL-TYPE STATION					
	DT&E	Test Hardware	TOTAL DT&E	Manu- factur- ing	TOTAL	DT&E	Test Hardware	TOTAL DT&E	Manu- factur- ing	TOTAL
Subsystem Level	618.5	242.7	861.2	52.6	913.8	686.5	563.2	1,249.7	245.0	1,494.7
Space Station Level	186.7		186.7	154.3	341.0	306.3		306.3	249.4	555.7
Facilities				45.0	45.0	59.4		59.4		59.4
Launch Vehicle & Launch Support				34.0	34.0				100.0	100.0
Operations				57.1	57.1				352.2	352.2
Program Management				85.9	85.9				140.4	140.4
TOTAL	805.2	242.7	1,047.9	428.9	1,476.8	1,052.2	563.2	1,615.4	1,087.0	2,702.4

TABLE 6-9
PROGRAM COST TRENDS
INDEPENDENT DEVELOPMENT VS MODULAR CONCEPT
(Millions of Dollars)

<u>Laboratory</u>	<u>Independent Development</u>	<u>Modular</u>	<u>Potential Cumulative Dollar Savings</u>	<u>Potential Cumulative % Savings</u>
One Compartment Dependent Laboratory	280	280	0	0
Two Compartment Independent Laboratory	740	740	0	0
Interim Space Station	1,500	680	820	32.6
Operational Space Station	2,700	1,220	2,300	44.1

Notes:

- Includes all DT&E and production costs up to launch.
- All space station programs were calculated using a uniform costing method.
- The One Compartment and Two Compartment Laboratories necessarily include the Apollo logistic system; other concepts do not include logistics.

both the sequential and the independent approaches. The results of the comparison show that with the selection of the modular approach it is possible to obtain a potential cumulative savings of about 40 percent.

6.2.8 Under-estimating Factors

Studies such as the one conducted by the Harvard Business School* indicate that schedules and costs based on historical data may be under-estimated by a factor of 3.2. If it is assumed that the program cost obtained in this study is under-estimated by factors ranging from 2.0 to 3.2, the total modular program cost could vary as shown in Fig. 6-7.

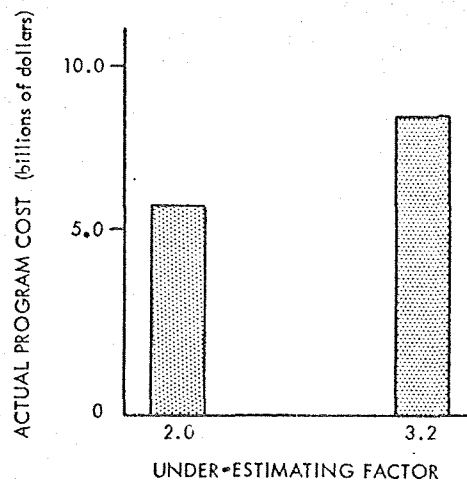


FIG. 6-7 POSSIBLE VARIATION IN PROGRAM COST

Investigation indicates costs could increase because:

- An optimistic subsystem development time has been assumed.
- A flight test program is required.
- The advances or application of technology are not as expected.
- The Apollo program is not operable at the estimated time periods.
- There are delays in funding for the modular program.

There are, of course, many more areas of cost sensitivity but the above appear to be most important.

*Peck, Merton J. and Sherer, Frederic M.; "The Weapons System Acquisition Process: An Economic Analysis."